

DESIGN OF READYMADE GARMENTS INDUSTRY FOR FIRE SAFETY



A Dissertation for the Degree of Master in Disaster Management

By
AHSAN FIROZ
10268004

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Postgraduate Programs in Disaster Management (PPDM)
BRAC University

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ABSTRACT

In Bangladesh businesses are growing at an ever fast rate. New businesses are opening everyday in every possible sector. Taking purchasing power parity into account Bangladesh is the 44th largest economy in the world. Bangladesh is also listed in the N-11 (next 11) by the Goldman Sachs Group, Inc. Among all the industries, at present textiles and readymade garments' industry are the top ones. Recently WTO has ranked Bangladesh as the 4th largest exporter of readymade garments' in the world. This sector contributes for 75% of foreign currency earning for Bangladesh. Textiles and Readymade Garments' sector contributes 13% of GDP and employs more than 3,000,000 people. It has brought benefit and blessings for millions of people in the country. This industry has played a significant role in elevating economic and living standard of millions of families all over the country.

Along with bringing blessing for the nation, textile and RMG industry also hold the record of experiencing some worst industrial accidents in the country. Taking advantage of poor surveillance of concerned authorities' rules, laws and codes are often violated in construction sector of our country and factory buildings are no exception. It is popularly believed and often proven true by incidences that the building codes are only maintained in paper works and hardly during the construction phase. Later as the owner focuses on the interior works, machine placement etc. the floors are often over loaded with machineries, causing more population load during operational hours, narrowing circulation spaces, thus making it difficult for the people to access the emergency route during an emergency. Many factories do not arrange regular drill; therefore the workers discover themselves in an alien situation whenever an emergency situation arises, causing panic, stampede etc. that further escalate the degree of casualty.

In the conditions as above the aforementioned thesis is proposed to evaluate the design of garments factories from a safety point of view especially in case of a fire out. The dissertation would focus on literatures, expert interviews and case study on previous incidence to find out the major reasons for casualty in case of fire in a RMG factory. The dissertation would then contain some software simulation with space syntax depthmap to evaluate the validity of the findings and would propose suggestions to alleviate the chances of casualty in RMG factories especially in case of fire.

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1 INTRODUCTION

Bangladesh, a country categorized in the list of developing countries is growing every day in terms of economy and business expansion. New businesses are opening each day in every possible sector ranging from agriculture to sophisticated information-communication technology (ICT) industry. At present out of all the businesses running in Bangladesh, the readymade garments¹ sector of the textile² industry has taken the lead in earning maximum foreign currency and employing a vast figure of populations in this sector. In the recent times Bangladesh showed significant improvement in various business sectors, readymade garments industry being the prime one.



Figure 1, RMG factory in Bangladesh (Mudditt, 2010)

1.1 Background

In April 2010, the USA based research agency Standard & Poor's (S&P) awarded Bangladesh a BB-rating (less vulnerable in the near-term but faces major ongoing uncertainties to adverse business, financial and economic conditions) for a long term in credit rating. In the context of South-east Asia the rank is below India but well over Pakistan and Sri Lanka. Bangladesh has been giving continuous efforts in elevating its economic condition. Foreign grant and loan has decreased from 85% in 1988 to 2% in 2010 (Rashid, 2009). The per capita income in 2009 was US\$ 610.10, whereas the world average was US\$ 7,880 (United Nations Statistics Division, 2009). However, according to IMF taking purchasing power parity in account Bangladesh is

¹ The part of the textile industry focused on manufacture of readymade garments

² The textile industry is primarily concerned with the production of yarn, and cloth and the subsequent design or manufacture of clothing and their distribution. Textile industry is a broad term covering all the sectors of clothing industry, in core terms readymade garments (industry) is one of the sectors' of the textile industry.

ranked as the 44th largest economic power in the world at US\$ 257 billion. Bangladesh is also listed in the N-11 (next 11) by the Goldman Sachs Group, Inc³.

Two third of the employment of Bangladesh is in the agriculture sector. According to FAOSTAT in the global context Bangladesh ranks as the 4th largest producer of rice. Bangladesh also ranks as the 11th largest producer of tea and holds high ranks in other agricultural productions such as jute, mango etc. Although agriculture sector ensures most of the employment, more than three quarters of export earnings of Bangladesh is from the readymade garments sector. At present readymade garments sector is the highest export earning sector of Bangladesh's economy (FAOSTAT, 2011).

Although agriculture sector ensures most of the employment, readymade garments industry has taken advantage of the potential of population density and is using it in its advantage as well.

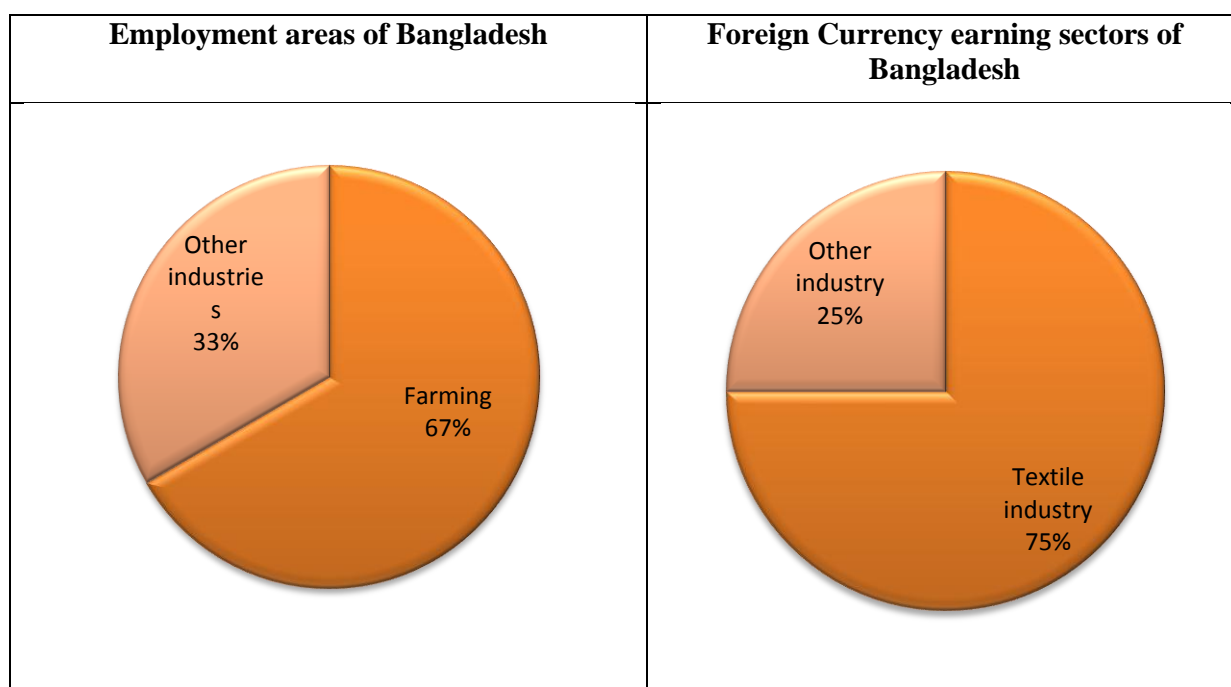


Figure 2, Employment and foreign currency source of Bangladesh

1.2 Statement of the Problem

In the list of good achievements Bangladesh has earned some bad records as well. There have been calamities like labor unrest for pay rise, over load of work to workers by managers, death due to accidents and disasters caused by collapse of buildings or major fire break out. It is popularly believed that in Bangladesh the safety of labors in readymade garments industry is often a neglected issue for the people who are in the driving hand of the industry. The recent

³ The Goldman Sachs Group, Inc. is an American multinational bulge bracket investment banking and securities firm that engages in global investment banking, securities, investment management, and other financial services primarily with institutional clients.

accidents such as fire breakout at “Hamim Garments” caused death of 26 people, injury to 100 others and a financial loss to the owner also. It is popularly believed that improper design, high population load and mismanagement of floors and circulation systems in the factories are major contributors to such incidences. In the conditions as above this dissertation proposes to evaluate the design of garments factories from a safety point of view especially in case of a fire breakout.

The guide law for construction of buildings in Dhaka and Chittagong, Mahanagar Nirman Bidhimala – 2008, has put on some parameters to architects, engineers and land developers to provide various life saving facilities in building projects at Dhaka and Chittagong as mandatory rules. An example of such parameter may be the mandatory requirement for emergency exits at every 23m interval (Mahanagar Imarat Nirman Bidhimala, 2008). At present the system is strictly followed during the construction phase of a building. But after the construction phase is complete, new tenants and floor owners take possession of the generally open floor spaces and design or decorate the interiors according to their own demand. This sometimes narrows down circulation zones or makes the circulation system complex making the journey to emergency exit a tough one. An earlier work with “Space Syntax- depthmap” by the author on interior spaces in offices (Vulnerability Study of Office Interiors in Dhaka in Case of Disaster) indicated such problem. As shown below, when considering the radial distance⁴ a floor or a zone in a building may appear safe, however when metric distance⁵ is considered the floor or the zone might not be considered. Now a study can be carried out to find out how and why the design process of readymade garments related factories lead to the evolution of such hazardous spaces and how the issues of hazard can be minimized.

⁴ radial distance – direct distance between two points irrespective of the obstacles on the way, requiring a person to change direction

⁵ metric distance – vector distance between two points i.e. considering the change in direction of motion for moving from point A to point B

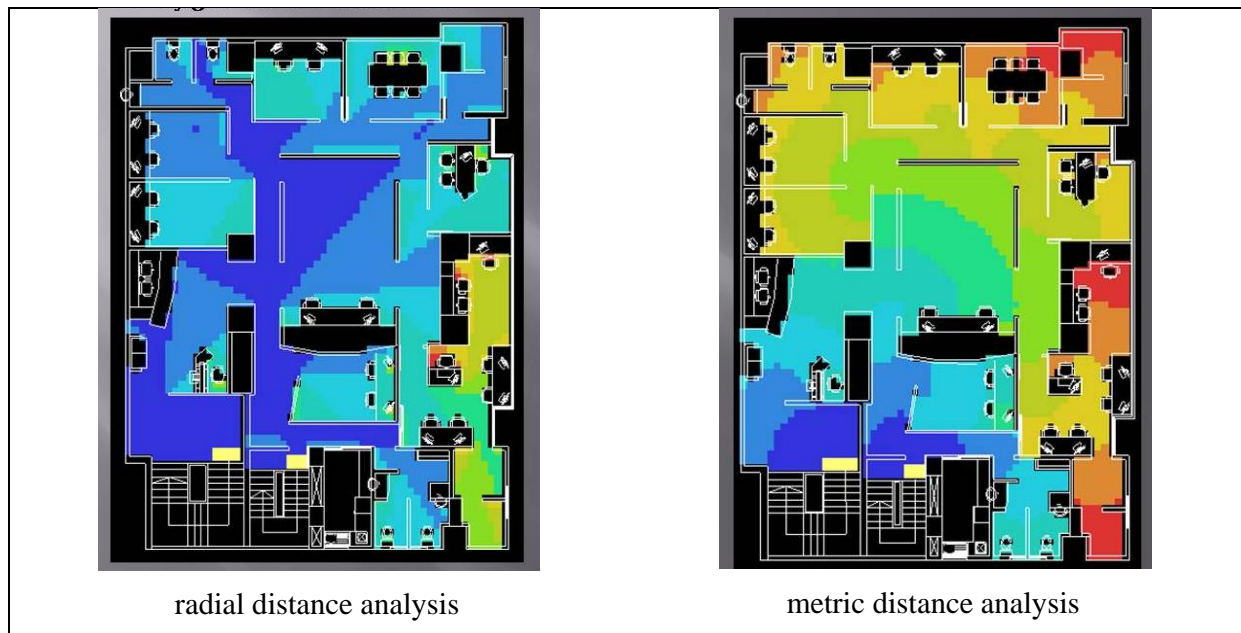


Figure 3, Difference between radial and metric analysis

1.3 Objective of the Study

The objective of the study is to evaluate the vulnerability to disaster of the readymade garments factory employees or workers' serving inside buildings at first through literature review etc. and later evaluating the concerned issues by conducting some software runs in *depthmap*. The software runs can generate some graphical representations of the actual disaster scenario and may help suggesting modification in design for reducing vulnerability of the users. *Depthmap* can produce outputs of various natures and types, however in this study, only evacuation is counted as major component for studying disaster vulnerability.

1.4 Definition of terms “textile industry” and “readymade garments industry”

Textile industry is primarily concerned with the production of yarn and cloth and subsequent design or manufacture of clothing and their distribution. The raw material may be natural or synthetic using products of the chemical industry.”Textile industry is a vast industry composing of various sectors such as knitting, weaving etc. It starts with the plantation of cotton tree and ends when a fabric reaches its final customer.

Readymade garments industry is originally a sector of the textile industry. However due to its own vastness nowadays RMG⁶ is also considered as an individual industry. While conducting the literature reviews for the origin of readymade garments industry, it was discovered that the early literatures refer to “textile industry” as a whole, rather than describing the “readymade garments

⁶ RMG - Readymade garments

industry” as a separate industry. It was during and after the industrial revolution that the readymade garments industry evolved as an individual industry.

2 RESEARCH METHODOLOGY

This chapter shortly describes the methodology following which the research will be conducted.

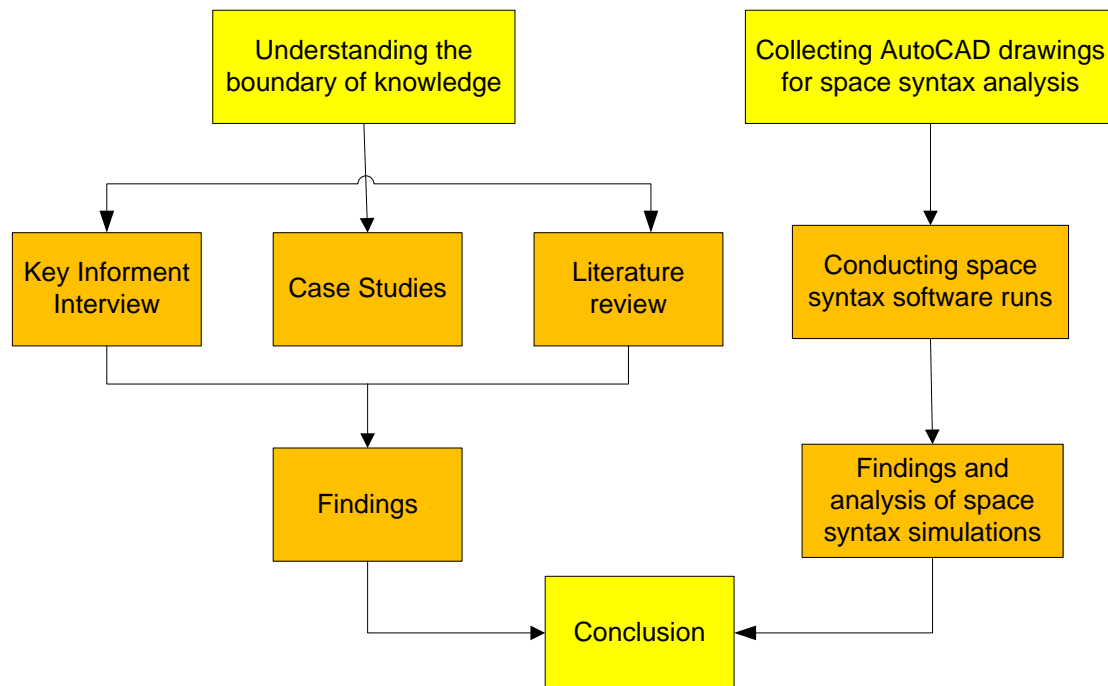


Figure 4, Methodology diagram

The methodology diagram for the dissertation is given above. As it can be seen in the illustration, the dissertation is divided in two major parts. One part (understanding the boundary of knowledge) consists of KII⁷, case studies and literature review. Chapter 3 and 4 is composed of this part of the work. Aim of this portion is to understand the existing boundary of knowledge from primary and secondary sources. The findings from this portion will be analyzed and compiled in chapter 4.5.

A vital part of the dissertation is the analysis of drawings of RMG factories with “Space syntax depthmap”. The focus of this part of the dissertation is to evaluate how the population load, interior layout pattern, machine layout and circulation system can contribute towards determining the vulnerability level of employees. The finding and analysis of space syntax outputs are compiled to give a conclusion. Chapters 6 and 7 compose of this part of the dissertation.

Finally the findings from primary and secondary sources and the findings from space syntax simulations are put together to form a concrete conclusion (Chapter 8) for “Design of Readymade Garments Industry for Fire Safety”.

Some important parts of the dissertation are discussed below:

⁷ KII – Key informant interview

Case study of previous events: Case study of accidents in RMG industry with relation to fire and evacuation has been studied and elaborated in detail. Reports on various accidents related to fire in textile industry were reviewed. Out of all, four case studies of high relevance to the topic are noted in section 4.4

Literature Review: For ensuring the understanding the existing boundary of knowledge, high emphasis was given in literature review. Many literatures on garments industry are available, but most of them focus on labor rights, gender issues etc. which are not relevant to this thesis. Less literature with relevance to design, safety and accident issues are found. While conducting the literature review focus was given on literatures containing safety issues of garments industries.

Key Informant Interview: Interviews were conducted with prominent RMG factory owners, designers and fire experts. Inputs of interviews have been a vital asset for the dissertation.

Space Syntax Analysis: AutoCAD drawings of some RMG factories have been analyzed in space syntax depthmap. The focus of this part of the dissertation is to evaluate how the population load, interior layout pattern, machine layout and circulation system can contribute towards determining the vulnerability level of employees. The system of conducting simulation, its parameter etc are elaborated in chapter 5.

Software Runs: The AutoCAD drawings are put in space syntax depthmap for simulation on the levels and factors of vulnerability. These are all elaborated and displayed in Chapter 06

Analysis: This chapter puts together all the findings from case study, literature review and space syntax software runs to construct a cumulative solution for attaining highest possible level of safety in RMG factories.

Conclusion: Finally findings from all the parts of the dissertation are put together to form a concrete conclusion for “Design of Readymade Garments industry for Fire Safety”.

3 READYMADE GARMENTS INDUSTRY

This chapter describes some historical background and current condition of the industry in both local and global context. As described in chapter 1.4 in some of the articles here the term “textile industry” is used to imply the readymade garment industry

3.1 Readymade Garments Industry in Global Context

3.1.1 History of the Industry

The exact date of when people started wearing clothes is not clear. There are different estimations about when people started wearing clothes. One of the studies says that men started wearing clothes 190,000 years ago. Anthropologists believe that the earliest clothes were made from skin, vegetation etc. (Travis, 2009).

Till the 17th century the textile industry was more of a cottage industry localized within certain transportable zones. The clothiers fabricated the cloth via various processing, all carried out in their courtyards. The clothiers would keep a portion of their product for the nearby market and carry most of their products on horseback to relatively distant areas for selling their products. There are also evidences of silk being imported to Europe from China via the Silk Road. Cotton being one of the earliest clothing materials in India made its first steps in Europe only during the medieval period. Later cotton came up as the prime clothing material globally.

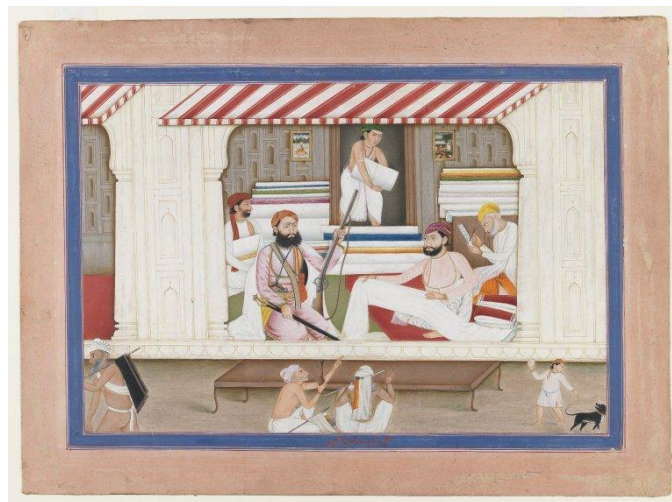


Figure 5, An Indian clothier shop in medieval times (Basarat, 1850)

3.1.2 Rapid Growth during the Industrial Revolution

The textile industry experienced booming growth during the industrial revolution of the 18th and 19th century. It is one of the industries to get maximum advantage from the Watt engine⁸. With the invention of the “flying shuttle”⁹ by John Kay in 1734 C.E mass production of yarn and cloth became a mainstream industry. The industry while getting geared up with advanced technology of those times also experienced labor protects against introduction of “flying shuttle” as the labors feared job loss. However, soon it was realized that because of the dramatic increase in rate of production the demand also increased. James Watt’s modified steam engine with separate condenser added another muscle to the industry in 1761. The industry received its biggest blessings in 1764 with the invention of “Spinning Jenny”¹⁰ by James Hargreaves. This invention elevated the thread production capacity of a single labor by eightfold and subsequently much further (Britannica Encyclopedia, 2011).

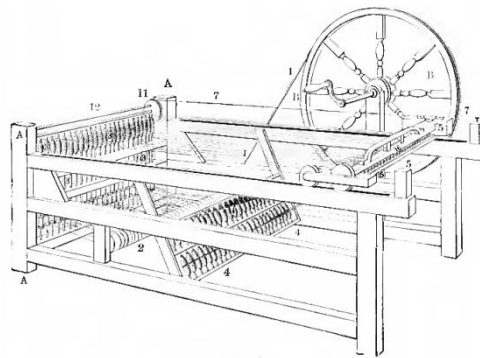


Figure 6, "Spinning Jenny", a magic machine during industrial revolution (Marsden, 1884)

⁸ The Watt steam engine was the first type of steam engine to make use of steam at a pressure just above atmospheric to drive the piston helped by a partial vacuum. James Watt developed engine based on the Newcomen engine of 1712.

⁹ The flying shuttle was one of the key developments in the industrialization of weaving. It allowed a single weaver to weave much wider fabrics, and it could be mechanized, allowing for automatic machine looms. It was patented by John Kay in 1733

¹⁰ The spinning jenny is a multi-spindle spinning frame. It was invented in 1764 by James Hargreaves in Stanhill, Oswaldtwistle, Lancashire in England. The device reduced the amount of work needed to produce yarn, with a worker able to work eight or more spools at once. This grew to 120 as technology advanced.

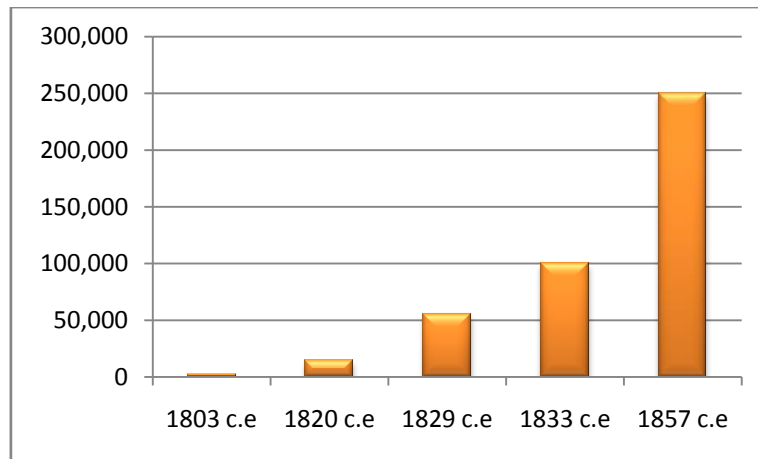


Figure 7, No. of looms in UK during 19th century (Hills, 1993)

Time line for milestone innovations:

Table 1, Milestone achievements in industrialization of readymade garments sector (Textile manufacture during the Industrial Revolution, 2011)

Year	Inventor	Machine
1734	John Kay	Flying shuttle
1761	James Watt	Modified steam engine with separate condenser
1764	James Hargreaves	Spinning Jenny

One of the earliest and still preserved textile mills to accommodate the technological marvels of the era of Industrial revolution is the Quarry bank Mill in Cheshire, England. It is now a museum of the cotton industry. It has been designated by English Heritage as a Grade II*¹¹ listed building.



Figure 8, Quarry Bank Mill, Cheshire, England (Merchant Taylors' School, 2009)

¹¹ Grade II* buildings are particularly important buildings of more than special interest; 5.5% of listed buildings are Grade II*

3.1.3 Current Global Scene of Textile and Readymade Garment Industry

Current statistics mostly compose of the economic and financial status. It is also discovered during the literature review that currently in a more liberalized environment, the industry is facing competition as well as opportunities. According to recent statistics, at present the global textile market is worth of more than \$400 billion. It is predicted that Global textile production will grow up to 50 % by 2014. The world textile and apparel industry has gone into a phase of transformation since the elimination of quota in the year 2005. Many new competitors as well as consumers have entered the global market with their immense capabilities and the desire to grow (Textile Exchange, 2006).

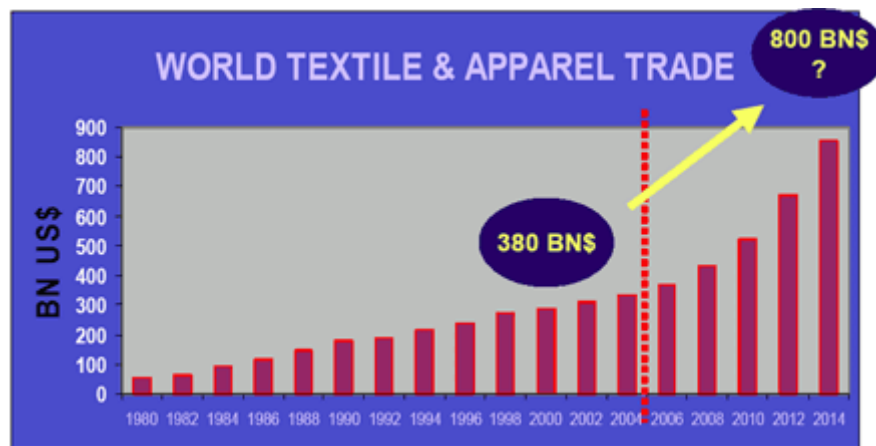


Figure 9, Trend of world textile and apparel industry (Textile Exchange, 2006)

The developed countries have a higher rate of consumption of textile goods (per kg per person) than the developing countries. The per capita (per kg) consumption of textile goods in developed countries is 17.7 whereas for developing countries it is 4.5.

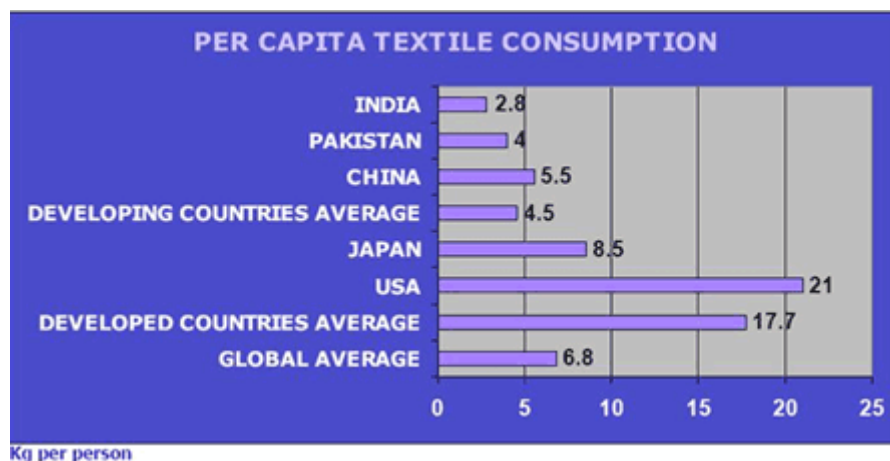


Figure 10, Per capita textile consumption (Textile Exchange, 2006)

3.1.4 Benefits and Dis-benefits of the industry

The readymade garments industry has blessed the civilization in many ways. Till the early days of industrial revolution it has accommodated employment for millions of people all over the

world. The industry has played a significant role in elevating living standard of the masses (mostly the middle class and lower income people). Even in the present days, readymade garments industry is still a major industry in the world and one of the highest earning sectors for many countries of the developing world such as Bangladesh, Cambodia, and Vietnam etc.



Figure 11, Anonymous readymade garments industry, Vietnam (Coldwell Banker, Vietnam, 2011)

On the antonymous side of bringing blessing for the masses, readymade garments industry is also responsible for causing some unforgettable disasters and severe violation of human rights in the history of civilization. During the time of its inception as an industry in Europe during the 18th century it invited workers from villages to the industrial towns. It showed and gave them good hopes and lives. However during the early days it had a very unpleasant working environment and was often called as sweatshop¹² to signify its murkiness. The collapse and subsequent fire of the Pemberton Mill¹³ in 1860 claiming 145 lives and the fire at Triangle shirtwaist Factory¹⁴ in 1911 claiming 146 lives are marked as black spots of the industry. In addition to these, suppression of labor rights, abuses of child labor are long known bad sides of the industry. Fortunately massive improvement has occurred in the safety and labor rights issue over the centuries. Significant reduction of the incidences as stated above has occurred.

¹² **Sweatshop** (or **sweat factory**) is a negatively connoted term for any working environment considered to be unacceptably difficult or dangerous. Sweatshop workers often work long hours for very low pay, regardless of laws mandating overtime pay or a minimum wage. Child labor laws may be violated. Sweatshops may have hazardous materials and situations. Employees may be subject to employer abuse without an easy way to protect themselves.

¹³ The **Pemberton Mill** was a large factory in Lawrence, Massachusetts, which collapsed without warning on January 10, 1860 in what is likely "the worst industrial accident in Massachusetts history" and "one of the worst industrial calamities in American history". An estimated 145 workers were killed and 166 injured.

¹⁴ Triangle Shirtwaist Factory fire, killed 146 garment workers on March 25, 1911. The fire led to wide-ranging legislation requiring improved factory safety standards and helped spur the growth of the International Ladies' Garment Workers' Union. As of 2002, the building's name was changed to the Silver Center for Arts and Science.

3.1.5 Technical Aspects of the Textile Industry

Textile industry is a broad term. It has numerous wings of source materials and systems of processing and production. To keep the chapter specific and focused only cotton is referred to as the source material and its processing is described in this chapter.

The textile industry as a whole begins from cotton tree and ends at the retailer shop from which the product is sold to end customer. In the long process there are numerous technical aspects involved. Six basic steps of textile industry (cotton based) are as below.

- a. Cultivation and harvesting
- b. Preparatory process
- c. Spinning
- d. Weaving
- e. Finishing
- f. Marketing

Of all the steps given above Step-a (cultivation and harvesting) occurs in cotton fields mostly under natural conditions. Steps – b, c, d and e occurs at various types of processing plants. Marketing is the absolute business part of the chain.

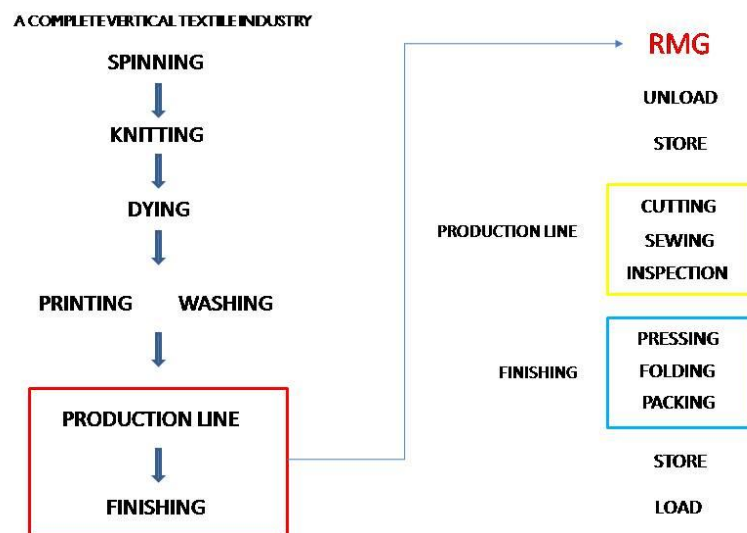


Figure 12, Order of events in readymade garments industry

3.1.6 Type of Readymade Garments and Their Capacity to Project Fire Hazard

The capacity of a readymade garments industry to project a fire hazard depends on the specific type of fabric being processed and the specific operation within the production system which a certain type of readymade garments is undergoing. For example, the risk of a fire related accident is high with synthetic fabric or felt materials. Reciprocally the risk is much less with natural

cotton. On the other hand, out of many operations conducted in a textile industry the risk of fire is one of the highest in the dying section, where fire may lead to catastrophic explosions (Warsaw).

3.2 Textile and Readymade Garment Industry in Bangladesh

3.2.1 Inception Phase of Textile and Readymade Garments Industry in Bangladesh

Readymade Garments industry had its roots in Bangladesh in 1980s. Actual reason for its rooting in Bangladesh dates back to the 1950s. In the 1950s the labors in western world became highly organized, forming trade unions. This and various other simultaneous movements' ensured stronger labor rights, higher wages, subsequently elevating the cost of production in a high rate. The investors in the west shifted to countries and places like Hong Kong, Taiwan and Korea for having low labor cost. In this scene, the Multi-Fiber Agreement (MFA¹⁵) was made in 1974 restricting the amount of imported clothes from developing to developed countries. This agreement imposed a maximum 6% increase of rate of export each year from developing to developed countries. Due to MFA and various other parameters, the investors shifted towards countries outside the parameter of MFA and other agreement(s) such as Bangladesh. In the 1980's when readymade garments industry just made its toddling footsteps in Bangladesh, some Bangladeshis workers received training from "Korean Daewoo Company". After accomplishing their training courses and returning to Bangladesh, some of them started their own business as entrepreneurs in the readymade garments industry (Commonwealth Secretariat, ed., 2004)



Figure 13, Readymade Garments factory in Bangladesh (Siliconeer, 2010)

¹⁵ The Multi Fibre Arrangement (MFA) governed the world trade in textiles and garments from 1974 through 2004, imposing quotas on the amount developing countries could export to developed countries. It expired on 1 January 2005.

At the time of its inception as an industry Tea and Jute were the largest exports earning sources of Bangladesh. The demand for jute was diminishing because of the admission of polypropylene products into the global packaging industry. With the diminishing international demand and constant threat of natural calamities such as flood jute soon lost its glory as the prime export product of the nation. The domestic demand for tea was also growing at a steep rate; therefore a significant amount of tea became consumed at the domestic market. With the drive out of jute and significant drop in export of tea, within two decades of its inception into the market readymade garments industry took the pinnacle as the prime export good of the country. Cheap labor and low conversion rate further catalyzed the growth of the industry by attracting foreign investors (Khondker, Razzaque, & Ahmed, 2005)

3.2.2 Present Status of Textile and Readymade Garments Industry in Bangladesh

Readymade Garments industry at present is the highest foreign currency earning source of Bangladesh. Recently WTO has ranked Bangladesh as the 4th largest exporter of readymade garments items in the world however The Economist has ranked Bangladesh as the 3rd largest exporter of readymade garments commodities. Three quarter of total export earning of the country comes from the readymade garments sector. In 2002 the total export earnings from readymade garments industry was US\$ 5 billion. In the fiscal year of 2009-10 the export earnings from readymade garments sector was US\$ 12.6 billion. In the 1980s there were only 50 factories employing a few thousand people. In 1990 the industry employed 400,000 people. The figure grew to 2 million in 2004 and at present the industry employs 3 million workers, of whom 90% are females. In general estimated populations of 10-12 million are benefitted from this industry. The number of enterprises in this sector elevated from 800 to 2000 in the span between 1991 and 2004. At present textiles and RMG sector contributes to 13% of GDP which was only 3% in 1991. Most of the readymade garments industries are owned by Bangladeshi entrepreneurs, leaving only 5% of the industries in ownership of foreign investors.

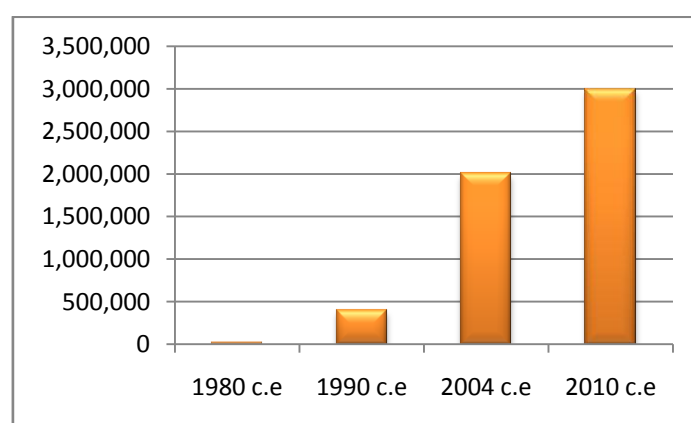


Figure 14, Rise in employment from 1980 – 2010

(Khondker, Razzaque, & Ahmed, 2005)

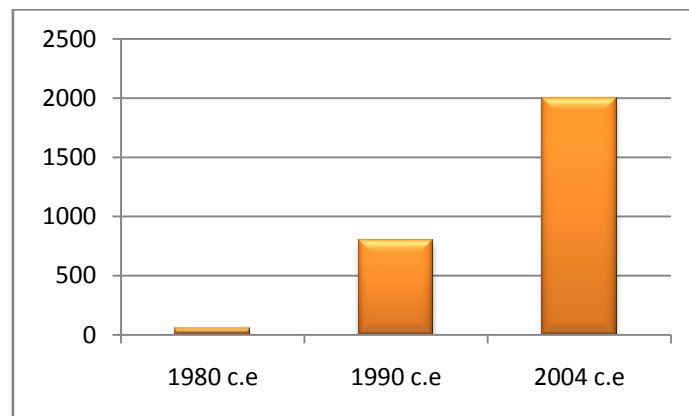


Figure 15, Rise in number of enterprises 1980 – 2004

(Khondker, Razzaque, & Ahmed, 2005)

4 ACCIDENTS IN THE INDUSTRY

The readymade garments industry has provided source of income for millions of people. It has been playing a vast role in elevating living standard of mass people, especially in the developing countries. On the other hand, the industry also holds the record of experiencing some worst industrial accidents as well. The accidents happened were of various types such as building collapse or fire breakout. The first disaster in the readymade garments industry took place at Pemberton Mill, Lawrence, Massachusetts in 1860 claiming 145 lives. In 1911, the Triangle shirtwaist Factory fire in New York claimed lives of 146 workers. The industry has been hit by various such disasters in Bangladesh as well. In recent time, the fires at Garib and Garib Sweater Factory and Hamim Group in 2010 are two of the worst accidents in the readymade garments and garments industry of Bangladesh. Some critics have put Bangladeshi readymade garments industry right up there with Chinese coal mining as one of the most dangerous industries in the world (New Internationalist Magazine, 2005).



Figure 16, Hamim Group's Factory in blaze, 14 December 2010 (Bilaj, 2010)

4.1 Accidents in Readymade Garments Industry of Bangladesh

It is popularly believed and often proven true by incidences that the building codes are only maintained in paper works and hardly during the construction phase. Later as the owner focuses on the interior works, machine placement etc. the floors are often over loaded with machineries, causing more population load during operational hours, narrowing circulation spaces, thus making it difficult for the people to access the emergency route during an emergency. After the collapse of Spectrum Sweater Factory and Shahrair Fabrics industry in Savar, Dhaka on 11 April 2005, which claimed 74 lives, Neil Kearney General Secretary of the Brussels-based International Readymade Garments, Garment and Leather Workers' Federation claimed that such accidents are *'the inevitable consequence of the race to the bottom now under way as a result of unregulated trade in readymade garments and clothing. ... [R]esponsibility lies with the World Trade*

Organization, which turns a blind eye to any suggestion that there is a link between trade and the conditions under which goods are manufactured, and with the Government of Bangladesh, whose authorities apply neither planning rules nor labor laws.’

Table 2, Deaths in fire accidents in garments industries in Dhaka (Fire Service and Civil Defence, 2011)

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999
	32	05	N.A	12	05	09	10	13	N.A	N.A
Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
	60	N.A	N.A	N.A	23	23	62	N.A	43	02
Year	2010	2011								
	50									

In Bangladesh, most of the accidents in readymade garments industry have occurred from fire and its subsequent impact on human mind (panic, stampede etc.). Other incidences like collapse of buildings (readymade garments industry) have also claimed high toll on human lives and property. In an interview a key personal of Fire Service and Civil Defense claimed that if incidences like stampede and panic could be eliminated than there might not have been any loss of human lives in most of the cases of fire in RMG factories. He also mentioned that if the management conducts regular drills and if all the workers are well trained and oriented, panic and stampede can be totally avoided. A video on a fire incidence in a factory was collected for the purpose of this dissertation. There within 2.5 minutes of ringing the fire alarm, all the workers were able to evacuate the building. All the workers evacuated smoothly without causing any panic or stampede. According to a report by “World socialist Web Site” since 1990 more than 350 people have lost their lives in garments factory fire in Bangladesh (Perera, 2010).

The table below provides year wise data on the number of accidents, their causes and frequency and casualties caused by the incidences:

Table 3, Accidents in textile and RMG industry 2007-2010 (Fire Service and Civil Defense, 2011)

Year	No. of incidences	Reasons for fire	Frequency	Percentage (%)	Injured	Dead
2007	326	Electric short circuit	229	70		
		Cigarette	32	10		
		Spark	25	8		
		Welding spark	18	5		
		Overheat	22	7		
2008	89	Electric short circuit	65	73	209	43
		Cigarette	9	10		
		Spark	4	4		
		Welding spark	5	6		
		Overheat	6	7		
2009	293	Electric short circuit	212	72	150	2
		Cigarette	28	10		
		Spark	19	7		
		Welding spark	21	7		
		Overheat	13	4		
2010	220	Electric short circuit	154	70	42	50
		Cigarette	22	10		
		Spark	17	8		
		Welding spark	12	5		
		Overheat	15	7		

According to the statistics of “Fire Service and Civil Defense¹⁶” on average 70% of all fires in textile and RMG industry occurred from electrical short circuit, 10% due to cigarette, 8% from other types of sparks, 5% from welding sparks and 7% due to overheating of equipments.

¹⁶ The primary organization responsible for responding to emergency situations such as fire break out and other accidents in Bangladesh

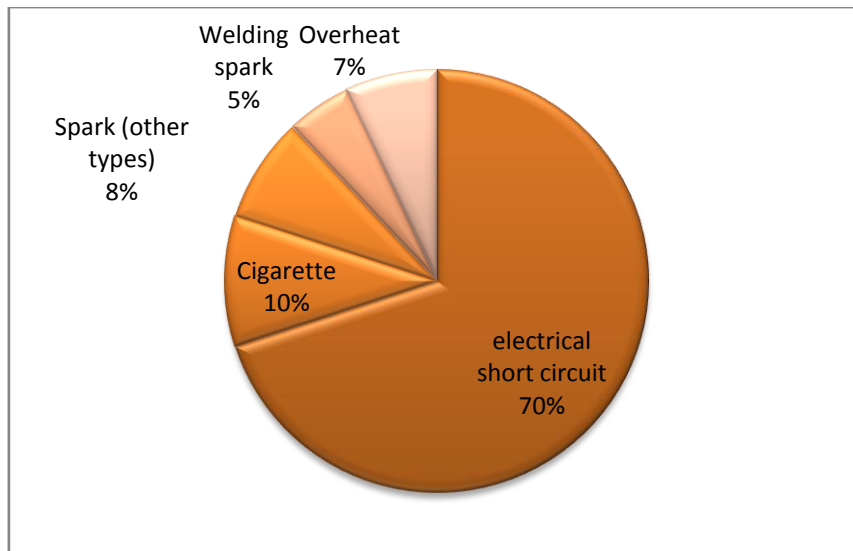


Figure 17, Reasons for fire at textile and RMG industries 2007-2010 (Fire Service and Civil Defence, 2011)

Figure 17 shows statistics of fatalities at readymade garments factories in Dhaka. Here it can be noted that more than two-third of all reasons of fire is electric short circuit. In a casual interview an electrical engineering consultant claimed the factory owners' attitude for saving construction cost as a triggering factor for this. The owners' in the intention to cut down construction cost often do not invite proper engineers or consultants to prepare proper electrical design for the factory. Even if the design is done, sometimes the owners do not install specified equipment, rather purchase substandard products rather than what is referred by the consultant. The substandard equipments fail to control proper electrical flow, causing over heat, spark or fire. On the other hand an industry owner claimed that sometimes the suppliers do not provide them equipments with proper specification with the intension to make extra profit. It is often impossible for the owners to find out if they have been provided with specified equipments or not since they do not have expertise in electrical design field. However, he also claimed that recently few of the factory owners have taken steps to ensure that only equipment and design specified by the consultant is realized at site

4.2 Literature review

For ensuring the understanding the existing boundary of knowledge, high emphasis was given in literature review. A lot of literature on garments industry is available, but most of them focus on labor rights, gender issues etc. which are not relevant to this thesis. Less literature with relevance to design, safety and accident issues are found. Therefore the literature review is kept here as a sub-chapter. This sub-chapter shortly describes the gist and findings from literature reviews. While conducting the literature review focus was given on literature containing safety issues of garments industries.



Figure 18, Stampede causes a large number of casualties

Qurratul-Ain-Tahmina and Khadiza Khanam (2001) conducted a study on various readymade garments industry in and around the capital. In most of the cases (focus of the study was on Choudhury Knitware) the reasons for casualty were stampede followed by locked / blocked exit route, panic, workers being unable to use the fire fighting equipments, suffocation and inhalation of toxic fumes etc. Industry managements were found to be totally unaware of the need and importance of the means of escape. Negligence of the authorities in preparing an emergency situation work plan and reharsing it in regular basis came out as major reasons for such catastrophic disasters. Similar findings came out in a later study by S Akther, AFM Salahuddin, M. Iqbal, ABMA Malek and N Jahan (2010). To add to these findings the later work by (Akther, Salahuddin, Iqbal, Malek, & Jahan, 2010) also placed two possible suggestions for reducing chances of accidents. (S Akther, 2010) discovered that some issues are easily identifiable and correctable¹⁷ whereas some issues require well planned operation¹⁸. The causes of fire and the reasons for subsequent casualties as found in both works of S Akther (2010) and Qurratul-Ain-Tahmina and Khadiza Khanam (2001) are given below.

¹⁷ Block of emergency exit and their subsequent clearance.

¹⁸ Other long term aspect such as training of the employees for reaction during an emergency situation, which requires well planned strategy and decision of the management.

(Akther, Salahuddin, Iqbal, Malek, & Jahan, 2010) further added causes such as unplanned work environment, disorganized workers, electric short circuit, faulty electrical wiring, smoking materials, boiler explosion, kitchen stove and carelessness, fire from existing structure, poor building design etc. as contributing sources for fire breakout in a garments factory. It is also found that cause of death is usually not the fire directly. Most of workers have died due to stampede, locked exit route, inadequate number of stairs, deliberately blocked pathways, smoke and suffocation.

S Akther (2010) further discovered that since many readymade garments factories are installed in city core areas in buildings originally designed as office space or residence, which are not designed for operation of factories and are naturally build in congested manner, fire can easily pass from one building to the next. The authors have marked the close positioning of readymade garments factories as a major threat to the industry as it may pass fire from one factory to the next very easily. At present the concern of the factory owners regarding fire hazard is increasing at a few areas. Some of the industries have ensured proper installation, arrangement and training of the safety equipments such as fire alarm etc. However proper planning and machine layout is still not practiced broadly and the authors believe that without a composite development such as proper planning of the factories, a full proof fire safe environment cannot be achieved. The findings of the paper in relation to fire safety are given below:

- a. Management is not aware enough for safety
- b. Not enough fire exit doors and ventilation for air circulation of industry building
- c. Most of the garment industries do not use safety sign according to the ILO conventions
- d. Most of the fire and smoke alarm bells do not work in garment industries and
- e. Many garment industries do not have fire and smoke alarm systems.

Recommendations of the authors: The recommendations in relation to the thesis topic are given below:

- a. Sufficiently wide fire exit doors and enough ventilation with proper maintenance for air circulation should be designed for industry building
- b. Regular fire drills should be held, minimum twice in a year
- c. Safety management training for all kinds of worker
- d. Proper exit sign and safety sign should be applied in appropriate areas of the industry
- e. All the buildings of garment industries should have proper announcement system as to how to get out of the buildings

From the literature review of various sources it is clear that the major reason for casualties in a fire breakout in a factory is not the fire itself. Rather the triggering components for fire (electrical short circuit etc.) and the subsequent impacts of the fire on human mind (panic causing stampede etc.) are the major reasons of casualties. The major reasons for fire are given below: gist reasons for fire and the causes are given below:

Table 4, Causes of fire in RMG factories

Causes of fire
Unplanned work environment
Disorganized workers
Electric short circuit
Faulty electrical wiring
Smoking materials
Boiler explosion
Kitchen stove and carelessness
Fire from existing structure
Poor building design
Lack of concern of industry owner in this issue

Table 5, Reasons for casualties in RMG factories

Reasons for casualties
Stampede
Locked exit route
Inadequate number of stairs
Deliberately blocked pathways
Smoke and suffocation

4.3 Safety Regulations for Readymade Garments Industry

As millions of people around the world work at readymade garments industries and the industries also contain certain characteristics and materials which may cause threat to life, most of the countries have their own codes, laws and regulations to ensure the safety of lives and properties in the industry complexes. Bangladesh being the 4th largest producer of readymade garments items also has records of some worst accidents in the readymade garments industry. This section elaborates the safety regulations for RMG industry of Bangladesh and some other countries.

4.3.1 Safety Regulations in Bangladesh

In Bangladesh “Bangladesh National Building Code” (BNBC) serves as the main guideline for ensuring overall safety standard of building. Unfortunately BNBC is considered as a code and is not mandatory to be followed by owners, designers or contractors. However the government of Bangladesh drafted a law in 2008 and passed it in the parliament in 2009, titled as “Mahanagar Imarat Nirman Bidhimala – 2008” (mentioned as bidhimala -2008 in the later parts of the dissertation). This set of law is mandatory to be followed in Dhaka and Chittagong city corporations. The law has been implemented and has shown effectiveness. The law has made some mandatory regulations for industrial buildings as well. The Annex I rule – 59,(f) (page- 3063 - 3072) (See Appendix I) of the law describes the rules and regulations about building safety and fire exits. For construction of factories within the “Export Promotion zones’ a separate set of laws is in practice titled as “Bangladesh Export Promotion Zone - Requirement for Self Constructed Buildings (mentioned as EPZ building rules in later parts of the dissertation). Apart from many commonalities the two codes have differences as well. In general the “Manhanagar Imarat Nirman Bidhimala - 2008” is both more detailed and more specific, contrary to the building code for EPZs. The Requirement for Self Constructed Buildings in EPZs is in an apparently brief format with a few gray areas. Therefore in this research the codes from “Mahanagar Imarat Nirman Bidhimala - 2008” is taken as standard for conducting the space syntax analysis towards the later part of the thesis. Some of the codes regarding emergency exit in direct relation to this paper is given below:

Table 6, Comparison between Bidhimala - 2008 and EPZ building code

Mahanagar Imarat Nirman Bidhimala – 2008	Requirement for Self Constructed Buildings in EPZ
Maximum distance from fire exit is 23 m (for factory buildings).	The distance from any point to the nearest stair shall not exit 100ft. (30.50m).
Provides a formula to calculate size and dimension of an emergency exit and provides proper specification for the same	Provides a “slab-based” chart for calculating stair width especially for buildings which will have more than 150 people (table 02).
Direct distance and length of line of travel is not defined separately.	C.4: fire exits from the building shall not be more than 150ft. (45.00 meter) from any point along the line of travel

Table 7, Chart for determining stair dimension, EPZ building rules

Persons	1st stair width (m)	2nd stair width (m)
Up to 350	1.50	1.25
450	1.70	1.25
550	1.80	1.40
650	2.00	1.40
750	2.15	1.50

The different rules for positioning of emergency exit are further described by the illustrations below.

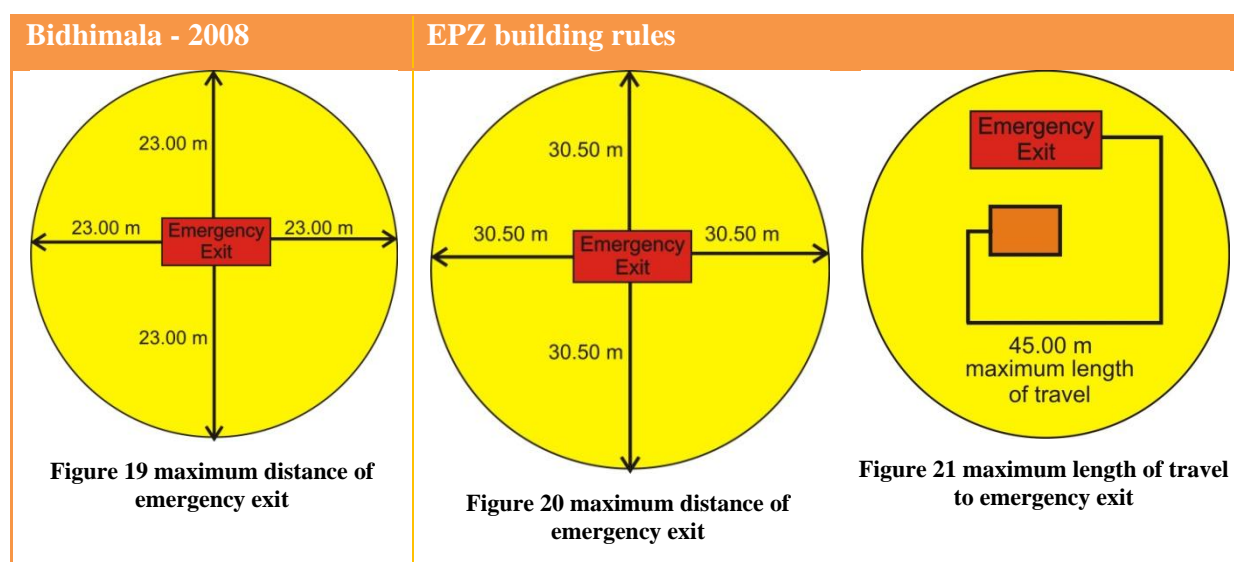


Figure 22, Illustrations showing difference between Bidhimala - 2008 and EPZ building rules

From the chart and the illustrations above it is clear that in Bangladesh there are different sets of rules for different areas. The reason might be to accommodate needs of specific locations while ensuring a safe environment. Since population density is higher in cities the rule is kept tighter

here. Although more detailed, specific and elaborate in many dimensions, having no defined difference between direct distance and length of travel, is a negative point of Bidhimala – 2008. The EPZ building rule is meant specifically for buildings to be constructed within the EPZs. It is written as a code especially for factory buildings. Although less elaborate than Bidhimala – 2008 in many dimensions, the segregation between direct distance and length of travel is a positive aspect of EPZ building rules.

4.3.2 Safety Regulations in Other Countries

Fire and safety code for other countries with high business in readymade garments sector was studied. Elaborate information on fire safety issues in industries in United States of America and Nigeria were found and reviewed in detail.

Part 11 of “The Investment Procedures, Regulations and Operational Guidelines for Free Zones in Nigeria (2004)” provide direction for construction and safety issues of factory buildings in Export processing zones of Nigeria. Unlike totally separate rules for city and EPZ areas in Bangladesh, in Part 11-4-B-(ii) the Nigerian code for export processing zones refer to the “Nigerian Building standards for factories” for all rules and regulations to be followed and implemented for construction of factory buildings within the EPZ campuses. In addition to this the guideline specifies some special requirements such as having all the permanent structures to be constructed with fire resistant materials in accordance with building and public health safety. The rule also commands the authority/zone management to keep check time to time to ensure that all regulations are fulfilled and followed (see appendix) (Nigeria Export Processing Zones Act No 63 of 1992, 2004)

In U.S.A, National Fire Protection Association (NFPA¹⁹) prepares standards and codes for ensuring fire safety in all possible aspects. NFPA has been giving high focus on the building sector (till its inception) to ensure fire safety. Fire safety in factories, which in this dissertation are the readymade garments factories are also within the umbrella of NFPA. Various regulations about fire safety are well specified and described in NFPA code book NFPA 101B, code for Means of Egress for Buildings and structures (1999) and NFPA 101® Lifestyle Code® (1997). The code is very specific on many important issues such as length, dimensions of egress route etc. The code also defines occupancy level at factory buildings etc.

¹⁹ The **National Fire Protection Association** (NFPA) is a United States trade association (albeit with some international members) that creates and maintains private, copy-written, standards and codes for usage and adoption by local governments

4.4 Case Study on recorded incidences

This section elaborates some accidents in the readymade garments industry. Section 4.4.1 describes two accidents that happened in the USA during the mid 19th and early 20th century. Section 4.4.2 describes two accidents in RMG industry that happened in Bangladesh over the last two decades

4.4.1 Two Major Disasters in the industry (International)

Pemberton Mill (1860): The first disaster in readymade garments industry took place at Pemberton Mill, Lawrence, Massachusetts. The factory was built in 1853 with \$850,000 by John A. Lowell and J. Pickering Putnam. In 1857 the factory was sold to George Howe and David Nevins, Sr. for a \$350,000 loss. The new owners jammed the factory with more machinery attempting to boost profit. At the time of collapse the factory had 800 workers, 2,700 spindles and 700 looms in operation. The factory collapsed without warning on January 10, 1860. An estimated 145 workers were killed and 166 injured in the building collapse and the subsequent fire breakout.

The mighty building was built only seven years earlier. It was five storied high, 280 feet long and 84 feet wide. Few minutes before 1700 hrs, the building collapsed while there were 800 workers inside. The two of the owners bought their families for a visit to the factory. Dozens of people died instantly as the building was falling down. About 600 workers were then trapped under the rubbles. Since it was winter, the rescuers set bonfire around the collapsed site to get light to assist their rescue work. At 2130 hrs, a lantern accidentally toppled over, putting all the rubbles in fire. It is reported that at least 14 people were watched by their close relatives while they burnt to death, unable of being able to escape from under the rubbles above them. The Pemberton Mill disaster claimed a total of 145 lives, injuring 166 more (by building collapse and fire). Later faulty columns and under-strength mortar were discovered as major reasons for the disaster. Overload of machinery and workers were also noted as triggering points for the disaster. The Pemberton disaster was one of the triggering events in the west for making of laws for safety at work place. It began the move against “sweat shop” factories which were gaining popularity among the investors, because of their cheap running cost. It also triggered movement for immigrant rights, who were forced to work in sweatshop conditions prior (and after) the Pemberton Mill disaster.

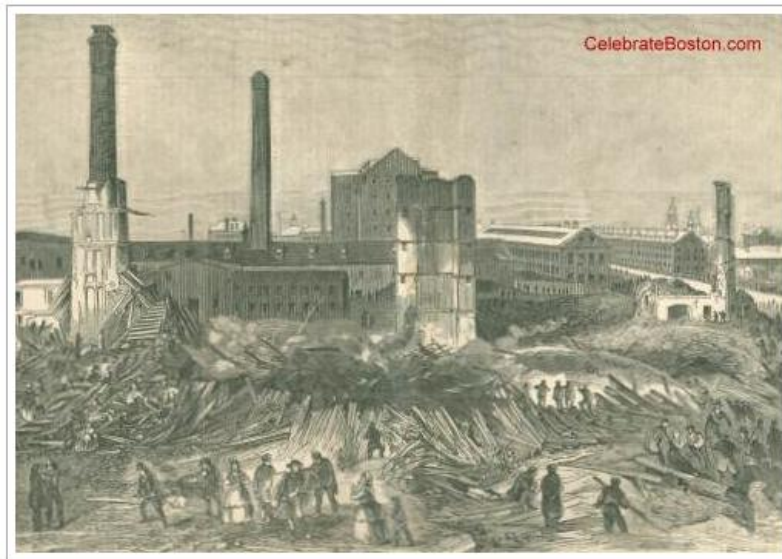


Figure 23, Collapse of Pemberton Mill, with Washington Mill at the background (Mill, 1860)

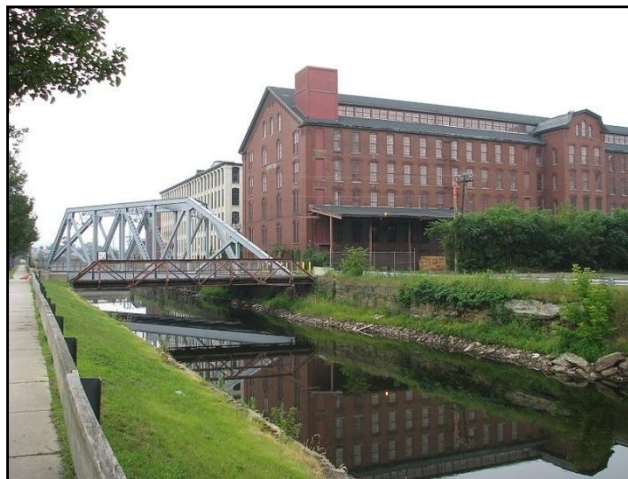


Figure 24, Pemberton Mill, Lawrence after reconstruction (Consentino, 2010)

Triangle Shirtwaist Factory (1911): The second accident and so far the most catastrophic one happened in New York at Triangle Shirtwaist Factory on March 25, 1911. The disaster is named as the “Triangle Shirtwaist Factory Fire”. The factory employed around 500 workers of whom 146 died due to fire and subsequent incidents. It is noted as the second worst industrial disaster in New York City, after the burning of the “General Slocum on June 15, 1904 – until the destruction of the World Trade Center ninety years later.

The fire is suspected to be ignited from un-extinguished matches or cigarette butt being thrown in a scrap bin which contained a large amount of cloth cutting. The fire was not the only source of destruction in the disaster. Three reasons were noted for causing deaths and casualties fire, smoke inhalation and falling from the upper floors. The building had multiple vertical exits but those were not able to serve efficiently due to unplanned control of exit ways. As the doorway to one of the major possible exit way and stair well was locked to prevent larceny many workers

were not able to evacuate who later choose to jump from the 8th, 9th and 10th floors of the building. The poorly built fire exit collapsed due to being over loaded.

It is unfortunate that incidences similar to Pemberton Mill or Triangle Shirtwaist factory disaster have happened in recent times in Bangladesh (almost a century later then the first incidences). After the two disasters mentioned above the workers, employers and the government of many states worked together to ensure a safer working environment. Many laws and codes were drafted regarding fire safety issues which have helped to significantly reduce such disasters.



Figure 25, Fire fighters desperate in extinguishing the Triangle Shirtwaist Factory (<http://www.ilr.cornell.edu>, 1911)



Figure 26, Triangle Shirtwaist Factory- after the fire was extinguished (<http://www.ilr.cornell.edu>, 1911)

4.4.2 Major Disasters in the Industry (Local)

Chowdhury Knitware, Narshingdi (2000):

The accident in Chowdhury Knitware at Narshingdi happened on 25 November 2000. The fire and its subsequent impacts killed 39 people. It was later confirmed by the concerned officials that only 4 died directly from fire. The rest of the people died due to stampede. On that evening a fire broke out on the 3rd floor of the factory. There were two vertical exit routes from the third floor, the main stair and the fire stair which terminated on the first floor of the adjacent construction site. Intended to prevent theft of valuable goods the fire stair was locked on flight above its final landing. Anyone taking the fire exit had to de-route for the main staircase once reached the first floor (the strategy did not work in panic situation). The main stair was open all through but was locked at the ground floor since there were ready products for export kept in front of the door way and the management feared theft. According to an eye witness a thread from a jersey caught fire and soon it was on blaze.”All the workers in the factory started to panic and run for life. Most

of the people took the fire exit route but were stranded behind the locked door (including one of the directors). People were not able to move backward to de-route because of huge crowd behind. People who took the main stair for evacuation were first stopped by the gatekeepers on the first floor landing as they also feared theft of product from the factory. The barricade of the gatekeepers was soon withdrawn, however the crowd got stranded behind the collapsible gate locked from outside. The main guard who carried the key was not found on spot. Later the lock was broken off to rescue the stranded workers.

Garib and Garib Sweater Factory (2010)

A fire at Garib and Garib Sweater Factory broke at 2130 hrs on Thursday, 25 February 2010. The fire claimed 21 lives and injured 30 more. Electric short circuit triggered fire the first floor. Highly flammable garment materials such as wool, threads and some other goods catalyzed the spread of fire all over a few of the floors. The workers were not able to evacuate from the building because the exit ways were blocked with materials and the exit doors were also locked (primarily to prevent larceny). The building was very poorly ventilated. Most of the trapped workers died from suffocation. Metal sheet structure was built at the rooftop constructed for the storage of highly flammable materials. The trapped workers were rescued after the fire fighters cut some of the metal grills meant for safety and protection of the building. In the mean time 21 workers lost life mostly due to suffocation. It was later discovered that the factory had a set up of fire fighting system, which remained “untouched” (or was inappropriate for the factory) during the catastrophe, as no one was trained on operating the fire safety gears. The figure below shows the triggering incidences of the catastrophe in gist

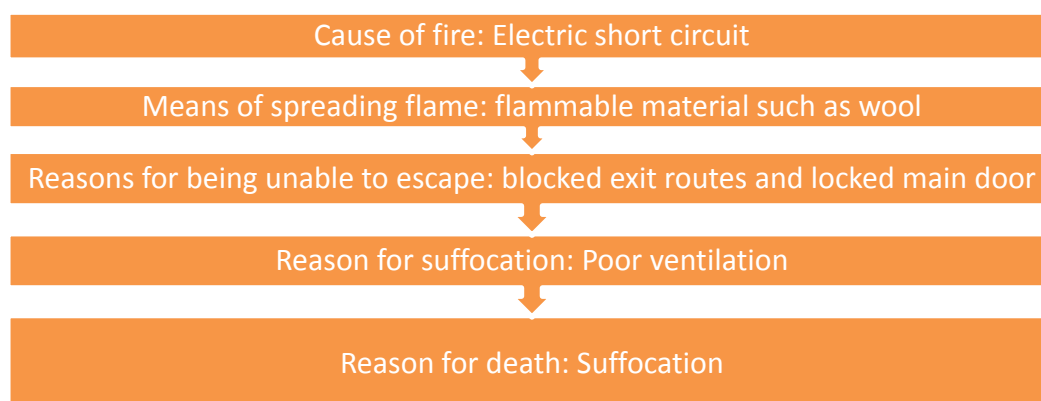


Figure 27, Summary of events at Garib and Garib Sweater Factory



Figure 28, Burnt interior of the factory (Gulftimes, 2010)



Figure 29, Burnt factory building from outside (www.cleanclothes.org, 2010)

Current situation at Garib and Garib Sweater Factory: In their website “Garib and Garib Sweater Factory now claims to have proper fire fighting equipments and are arranging regular drills and trainings to their workers.



Figure 30, Briefing session by fire fighters to workers at Garib and Garib (www.garibngarib.com, 2011)



Figure 31, Instructions for operating fire fighting equipments at Garib and Garib (www.garibngarib.com, 2011)

Recent actions claimed to be taken by Garib and Garib according to their webpage are given below:

- Increased fire fighting equipments
- changed their electrical system and installed bus bars
- Purchased new IPS Backup for its fire alarm and emergency light.
- Training to employees twice per month.
- Daily Checkup for all electric wire and equipments

4.5 Findings from Case Study and Literature review

It can be concluded from the case studies literature review that fire itself was not a major source of destruction or casualties. In most cases it was negligence of human actions or panic reaction that caused tremendous loss of lives and properties. The chart below and its succeeding pie charts further strengthen this point.

Table 8, Major accidents due to fire in RMG industry (2000-2010) (Akther, Salahuddin, Iqbal, Malek, & Jahan, 2010)

Date	Place	Dead	Injured	Cause of fire	Reason of death
14 December 2010	Hamim Garments Ltd. Ashulia, Savar, Dhaka	26	100	<ul style="list-style-type: none"> Oven in canteen kitchen 	<ul style="list-style-type: none"> Suffocation Panic (jumping from higher floors)
25 February 2010	Garib and Garib Sweater Factory	21	10	<ul style="list-style-type: none"> Electric short circuit Storage of inflammable material (wool) 	<ul style="list-style-type: none"> Suffocation Lack of ventilation Locked exit Exit routes blocked with other materials
06 March 2006	Salem Fashion Wear Ltd. Gazipur, Dhaka	03	50	<ul style="list-style-type: none"> Unknown 	<ul style="list-style-type: none"> Exit blocked Smoke Stampede Fire panic
23 February 2006	KTS RMG Industries, Chittagong	91	400	<ul style="list-style-type: none"> Electric short circuit 	<ul style="list-style-type: none"> Exit door locked Fire Suffocation stampede
11 April, 2005	Spectrum-Shahrier Factory	74	100+	Un-applicable	<ul style="list-style-type: none"> Building collapse
2005	Shan Knitting	23		Unknown	Unknown
03 May 2004	Misco Super Market, Dhaka	09	50	<ul style="list-style-type: none"> False fire alarm 	<ul style="list-style-type: none"> stampede
08 August 2001	Mico Sweater Ltd. Mirpur	28	100	<ul style="list-style-type: none"> Unknown 	<ul style="list-style-type: none"> Single exit locked
01 August 2001	Anonymous Factory in Kafrul	26	76	<ul style="list-style-type: none"> Unknown 	<ul style="list-style-type: none"> Smoke stampede
25 november 2000	Chowdhury Knitware	53	100	<ul style="list-style-type: none"> Short circuit 	<ul style="list-style-type: none"> fire smoke stampede
28 August 2000	Anonumous Garment Factory at Banani	12	45	<ul style="list-style-type: none"> Unknown 	<ul style="list-style-type: none"> Suffocation stampede
2000	Anonymous Factory, Dhaka	48	70	<ul style="list-style-type: none"> Boiler burst 	<ul style="list-style-type: none"> Trapped in locked

Table 9, Total casualty from fire in RMG industry (1991-2011)

Total death in fire related accidents (1991-2011):	340
Total injured in fire related accidents (1991-2011):	825

The chart above shows some of the major accidents that occurred in RMG industry over the last decade, due to fire (except Spectrum-Shahrier Factory). The reasons for fire and the reasons for death are presented in separate columns. Out of twelve incidences summarized above, fire was one of the direct causes of death in just two incidences (Chowdhury Knitware²⁰ 2000 and KTS RMG Factory 2006). In most of the cases deaths and injuries are due to panic, stampede, suffocation, being unable to exit etc. The following pie-chart further elaborate this point.

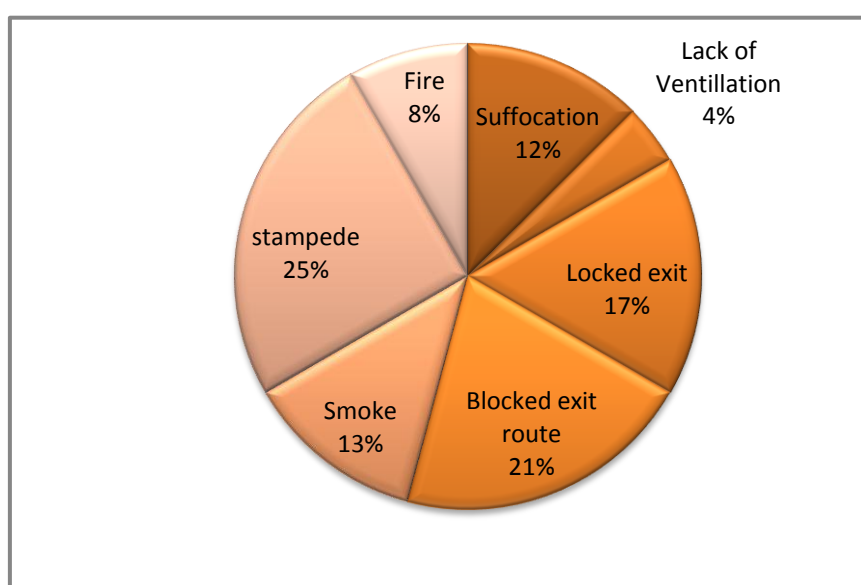


Figure 32, Reasons for death due to fire

From the above pie chart it can be deduced that fire itself was the cause of casualties in only 8% of the cases. The post-actions due to fire are shown to be the major reasons for casualties. It can be seen that largest amount of casualties happened from stampede (25%), succeeded by blocked exit route (21%) and thirdly locked exit ways (17%). These are more of circulation issues which can be solved in design phase. All together the above issues contribute to causing 63% of all casualties. This fact strongly speaks for the point that it is an extreme necessity in case of Bangladesh to carry out experiments to evolve a workable emergency exit plan keeping in consideration various aspects of circulation and population load. Smoke caused 13% of all casualties; suffocation caused 12% and lack of ventilation contributed for another 4% of total casualties. Like the issues regarding circulation, the above three reasons can be put under one umbrella named as “ventilation issue”.

²⁰ At Chowdhury Knitwear 4 Of 53 victims died from fire

The major reasons for casualties are shortly described below²¹:

Stampede (25%): Stampede has occurred in RMG industries due to lack of training and insufficient exit ways. It was understood from various literature reviews and case studies that whenever a fire broke out in a factory with untrained workers²², panic spread out immediately making the situation even worse. People started running around randomly without knowing which way to run, causing someone to fall down thus triggering a chaotic situation. This issue is further escalated if the floor is unplanned.

Blocked exit route (21%): In some cases (e.g. Garib and Garib 2010) the workers were not able to escape as the exit routes were blocked with cartoons of finished product. There were only a few cartoon placed in front of the exit door. Even though there were only a few cartoons in front of the exit way, due to panic, suffocation and smoke no one was able to remove those to make the path clear. This is a major cause of casualties in RMG industry.

Locked exit route (17%): In some cases (Chowdhury Knitwear, 2000) the workers were able to evacuate from the floor where the fire ignited, but when they reached the ground floor for exit the building they were trapped behind “locked exit doors”. The emergency exit doors were kept locked with the intension to prevent larceny or theft. It was assumed that during any emergency the security personal in possession of the keys would open the lock. The ideas were never trailed or experimented and did not work in emergency situations.

Smoke (13%): Here smoke is referred to toxic or non-toxic fumes which are generated when certain types of garment fabrics. The toxic fumes cause death from inhalation. Non-toxic smoke does not take life directly but significantly reduces visibility triggering to stampede etc.

Suffocation (12%): Suffocation is a major reason for casualties. It has been discovered that suffocation occurs because of presence of smoke or when too many people get trapped in a small space. Mostly people suffocate because of presence of smoke. While an area is in fire, the level of oxygen decreases and gases hazardous for human lives are generated.

Fire (8%): Fire itself is not a major reason for casualties. Direct casualties due to fire are only 8%.

Lack of Ventilation (4%): Due to lack of ventilation toxic or non-toxic gases get trapped inside the buildings causing people to die from inhalation of toxic fumes and suffocation.

²¹ The write up is based on literature review, expert, official statistics, case studies, eye witness and victim reports

²² Untrained from the perspective of fire safety, evacuation etc.

Seven factors contributing to casualties due to fire are discussed above. Few of the points with common characteristics are clustered as below.

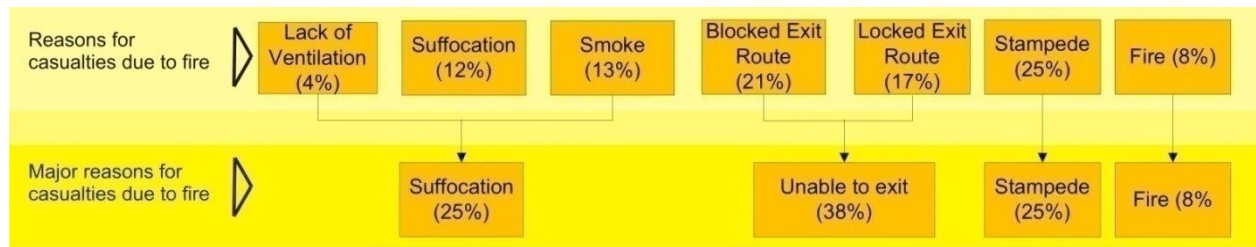


Figure 33, Reason and major reasons of casualties due to fire

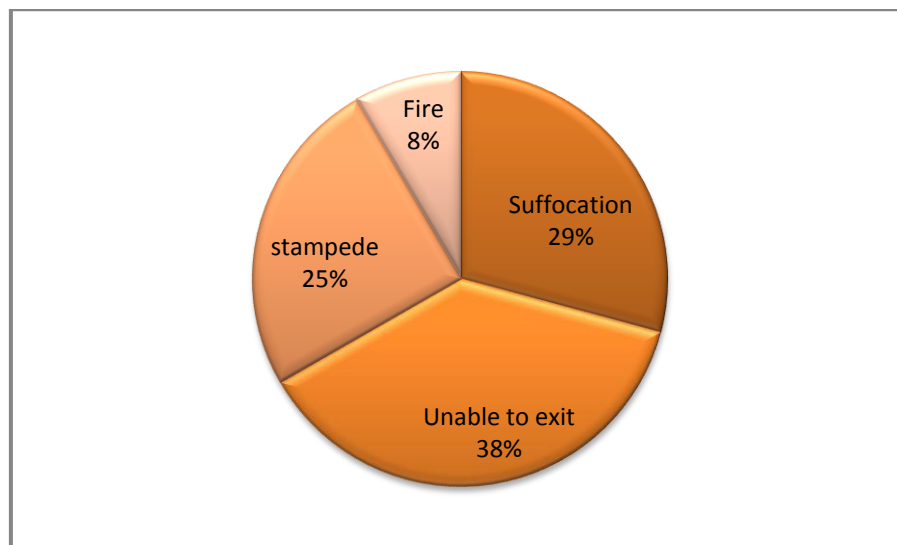


Figure 34, Major reasons for casualties due to fire

The pie chart above is made, based on the clustering of reasons for casualties (figure 35). The post-actions due to fire are shown to be the major reasons for casualties. It can be seen that largest amount of casualties happened from being unable to exit (38%), suffocation (29%) and thirdly stampede (25%). All three major reasons for casualties can be solved by architectural and design interventions. Here we see that two major elements of design are contributing to high casualty rates:

- a. Circulation: unable to exit and stampede
- b. Ventilation: suffocation

The problems shown above can be solved in design phase. The two issues related to circulation (unable to exit and stampede) contribute to a total of 63% of deaths or injuries. This fact strongly speaks for the point that it is an extreme necessity in case of Bangladesh to carry out experiments to evolve a workable emergency exit plan keeping in consideration various aspects of circulation and population load. In the next chapter “space syntax depthmap” will be used to demonstrate how casualties due to being unable to exit and stampede can be reduced or eliminated. In the

conditions as above the aforementioned thesis is proposed to evaluate the design of garments factories from a safety point of view especially in case of a fire out.

4.6 Problem Identification

From all the studies done earlier (case studies and literature reviews) and the statistics presented above it is clear that fire itself is a minor reason for causing death and injury. Major reason for the casualties are stampede (25%) and unable to exit (38%) totaling to 63%. Both these issues may be solved from design perspective. In such scenario “space syntax – depthmap” software run might be the most rational and appropriate idea to find out the problems regarding the exit system and circulation pattern of the buildings.

4.7 Research question

Based on the introductory study, literature review, case studies, KII etc. a research question as below is established:

How design aspects may reduce or eliminate vulnerability of readymade garments industry employees in case of fire?

5 INTRODUCTION TO SPACE SYNTAX SYSTEM

Space Syntax is a software system developed in 1990s' by the University College of London to study various movement pattern of people in both macro and micro scale i.e. to project expected movement pattern of people in a very large city as well as a small residence or a shop.

The space syntax program works in both *axial* and *isovist* format. Here, for the study of RMG factory interiors the *isovist* format is used. Within the *isovist* format *VGA* analysis system is used to study the RMG factory interior spaces. For this study only two of the software's tools are used. These two are named as "Angular analysis" and "metric analysis."

An angular step depth analysis measure includes the diagonal distance of a point from the exit. An angular analysis may not take into consideration the number of twists and turns required for reaching the exit from a given point. It may not also take into account factors like small exit, high population density etc.

The metric step depth analysis takes into account the metric distance of a point from the exit. It takes into account all the possible obstacles and the necessary twists and turns required to reach exit from any given point within the graph. To reach up to the level of angular and metric analysis many pre-steps are necessary which are elaborated in chapter 5.2

5.1 Conceptual framework for Space Syntax Analysis

The conceptual framework of this study is to identify the true vulnerability of RMG workers and their possibilities of survival by providing some suggestions. Technically the conceptual framework of space syntax analysis for this dissertation can be written as to analyze and re-analyze space syntax outputs (Experimental Method)

At first the dissertation has identified the reasons for fire and the reasons for consecutive casualties (elaborated in chapter 4.2, 4.4 and 4.6. This part is based on literature review, interview, case studies etc. As described in chapters 4.2, 4.4 and 4.6 the reasons for fire and casualties are already established. It is already established that management issues contribute more to the loss of lives rather than the fire itself. The dissertation would now focus on whether the internal design aspects may contribute towards determining the vulnerability of workers, especially in case of fire. In chapter 6, AutoCAD drawings of various garments factories are analyzed with Space Syntax Depthmap to evaluate their level of vulnerability. The Space Syntax Depthmap will help us analyze if the design of the building poses any threat to its occupants. The software would give results in two modes (based on input given).

- a. Based on input set according to rules and regulations, it would tell us if any rule is violated while in design phase or if the building is constructed properly, following the rules and regulations
- b. Based on its default comparative analysis system, the software would tell us if there are any chances of life risk due to design irrespective to whether rules were followed or not during the construction phase

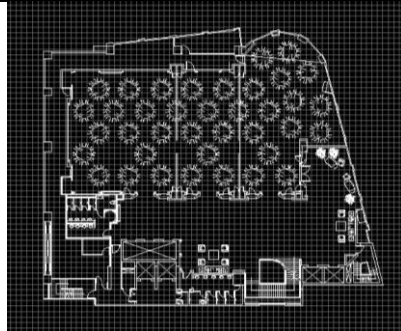
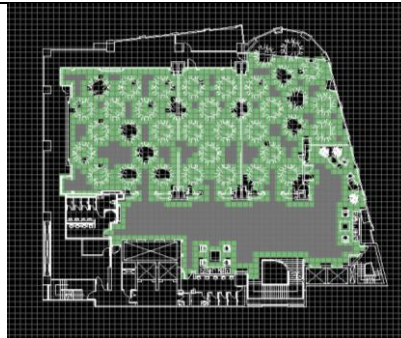
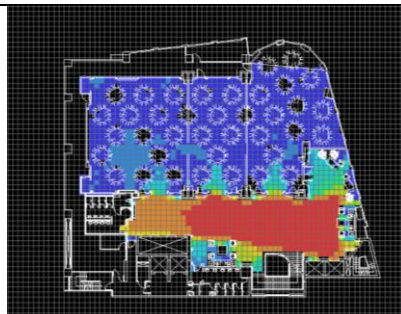
The procedure of Space Syntax Depthmap software runs are elaborated in Chapter 6. However, a few parameters given to the software based on findings, literature review and case study are elaborated below:

As mentioned in Chapter 3.3.2 the code for construction of factories vary in Bidhimala – 2008 and EPZ building rules. Bidhimala – 2008 requires one emergency exit every 23 m whereas it is 30 m in EPZ building rules. Moreover the EPZ building rule sets a maximum travelling distance of 45 m from the furthest point to an emergency exit. Length of travel is not clearly defined in Bidhimala – 2008. The analyses are conducted with 23 m radial distance.

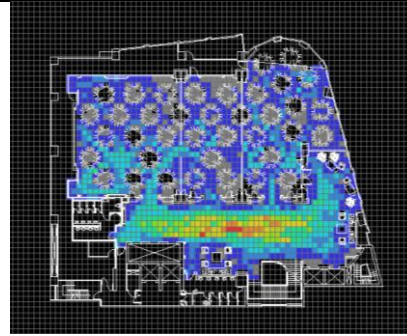
5.2 Demonstration on Space syntax Depthmap

Figure below gives an idea of how space syntax depthmap software works in its very basic format. The following analysis is carried out on a hotel ballroom and the lobby space in front of it.

Table 10, Steps of work of Depthmap

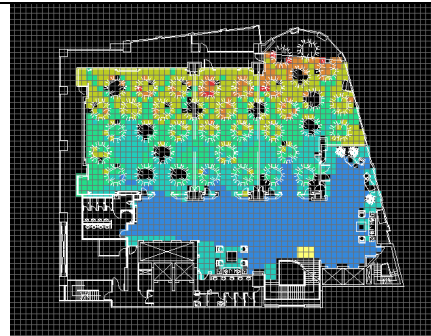
Task	Output
Step -1: converting the drawing files to the proper format	
converting the drawing files to the proper format	
Step – 2: Selecting the area to be studied	
The area to be studied is highlighted with “fill tool”. For the study of safety of interior spaces, Depth map VGA tool is used in the study. First floor of a Hotel is chosen as a demonstration. For the purpose of demonstration VGA tool is used. At first the overall move ability in the whole floor is studied	
Step – 3: Making visibility graph	
An overall visibility pattern is generated by the computer. The ballroom is shaded in blue and the lobby in shades of red. Since the analysis is conducted with furniture layer ‘on’, depthmap has considered them as obstacles in the ballroom. In relative terms the lobby has less obstacles therefore depthmap has given it a higher visibility rating.	
Step – 4: Default agent analysis	

Agent tool is an element in the software which gives us an image of which zones in floor people hit up the more and where the least. At this stage the default agent tool is run. By default people are moving from any location. It is evident that there is more pressure on the lobby. The software automatically detects that moderate and safe movement goes on inside the ball rooms, however detects a relatively congested movement in the lobby zone.



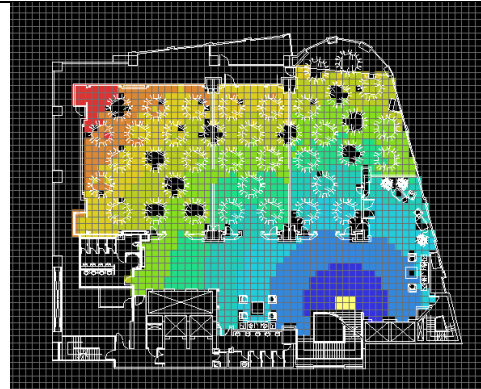
Step – 5: Running agent tool from specific locations (visibility/angular):

In the earlier step, an average movement pattern was generated by the software. Now, the beginning point of the movement and visibility are spotted by the user. It must be mentioned that in this step and the later, reverse counting is done. The software generates color gradient, based on moving an agent from the given spot to the furthest zone. Here we are the same technique is used to derive the opposite conclusion, as to see from which zone reaching the given spot is most difficult.



Step – 6: Running agent tool from specific locations (metric):

According to the metric step depth, red gradients are at a higher risk. The metric step depth considers all the obstacles that a person has to counter before reaching the desired location, which in this case is the main stairway.



Steps 1-6 shown above are basic steps of analysis. Here the software works on a comparative basis i.e. it creates the color shade based on its own understanding of the plan given for analysis. For example, it would give a red shade to the apparently most distant part of the plan from the exit. The output as mentioned above may not also be considered incorrect as well; although the analysis is based on the understanding of the software itself in relation to the whole area of the given plan. The same color shading may be found if two similar plans are given for analysis with their scales different as shown in Figure 35.

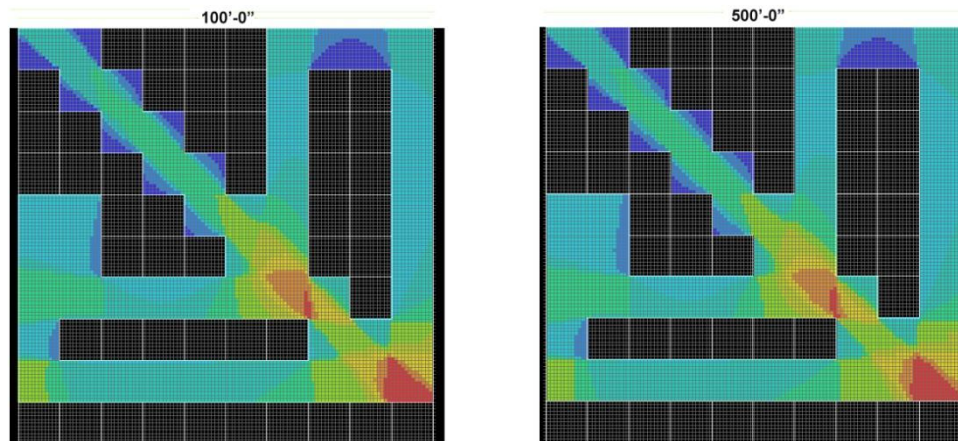
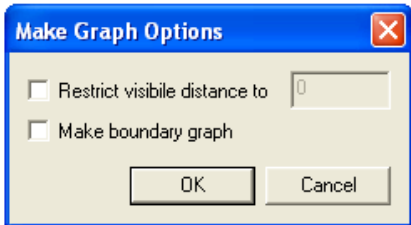
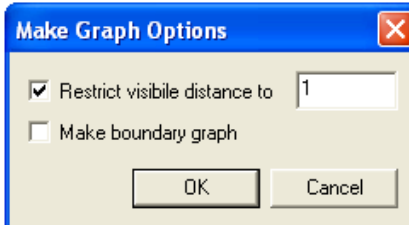


Figure 35 Comparison between two similar plans with different scale (no difference in shading as the analysis was run on a relative scale of individual plans)

To clear up the issue of drawing scaling the following example is given: The illustration below is of the same example as in Table 10 but in a different scale (more proper scale for depthmap²³). The drawings in Table 10 are of arbitrary scale²⁴. Table 11 below describes few input points which were changed for the later software runs. On the left column the default settings as applied to software runs in are shown. On the right column the altered inputs are shown.

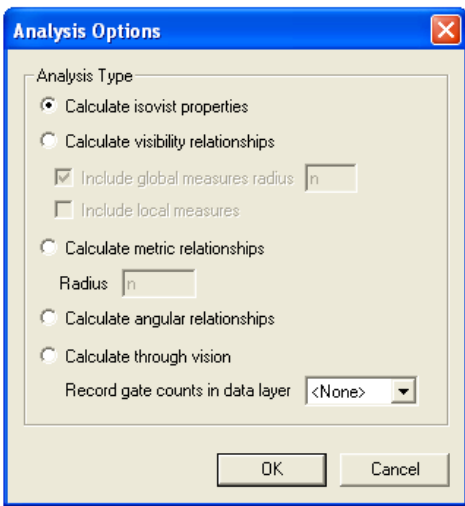
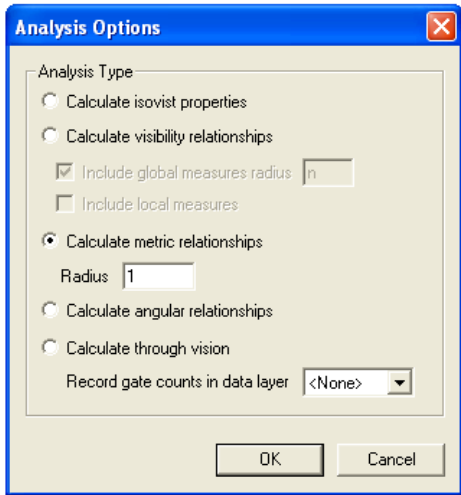
Table 11, Difference between default setting and altered setting in Space Syntax Depthmap

Default setting	Altered setting
	
<p>Here the visibility graph is prepared at the default scale</p>	<p>The visible distance from one isovist point from the next is set at 1m²⁵. In this analysis the isovists movement is much restricted from the default one</p>

²³ Depthmap works best if the scale is set in metric meter

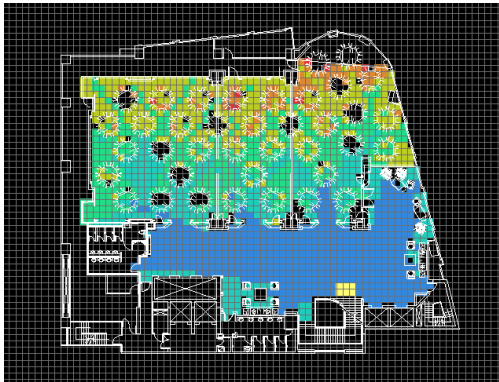
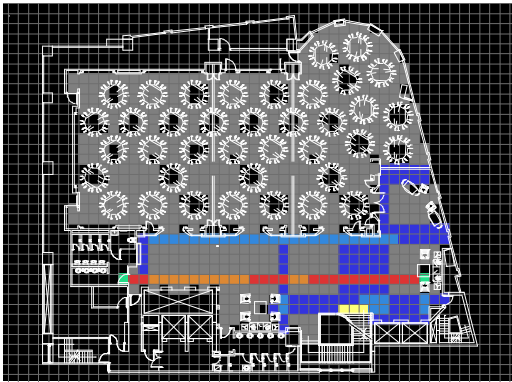
²⁴ Depthmap works best with meter scale. The drawings in table 4 are in millimeter scale. In the later drawing the unit is changed to meter and the drawing is scaled accordingly.

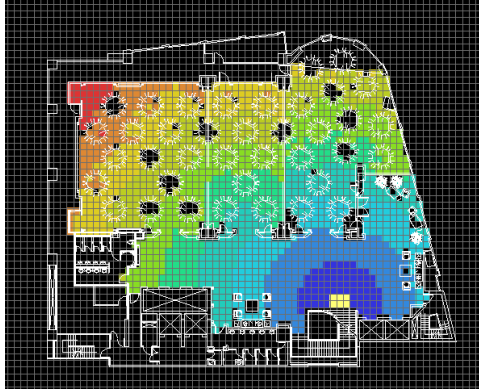
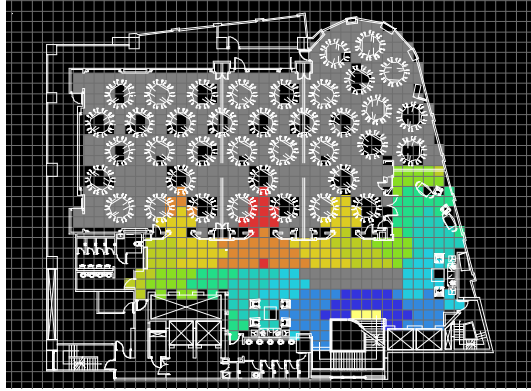
²⁵ The VGA graph grid in “space syntax depthmap” is set at (1,1) so every grid (representing one isovist each) is 1m X 1m.

Default setting	Altered setting
	
<p>Here, while running the visibility graph analysis the default setting is at “Calculate isovist properties”.</p>	<p>Here the default setting is altered. For running the visibility graph analysis “Calculate metric relationship” is checked and the radius is set at 1m.</p>

Some significant change in output due to altered input is given in Table 12. The changes in result are cumulative effects of the alterations shown in Table 11.

Table 12, Difference in Analysis between default setting and altered setting in Space Syntax Depthmap

Default Setting	Altered Setting
Agent analysis from selected location	
<p>Here the software moved the agents based on its default settings. The agents moved all around the plan, creating some shades of red (indicating relatively higher concentration) at a few places.</p>	<p>Here the agents’ movement radius is restricted to ‘1’. The agents made very restricted movements from the location of release</p>
	

Default Setting	Altered Setting
Step depth from selected location	
The isovists moved up to all open ends of the plan, accessible from the stairway	Here since the visibility and the isovist movement were restricted to '1', the isovist's were not able to move much. The red shade stated much short of distance than the default analysis. Also as the
	
It is clear from the two images that the results varied significantly due to change in inputs given to the software. In the default analysis the software moved its isovists all around the plan whereas in the altered study, the isovist movement was restricted to '1' which in this case is much lower than the default movement capacity.	

5.3 Literature Review on Space Syntax System in Association to the Project

This section elaborates the source and findings from various literatures which are reviewed in the course of preparing this proposal. High focus was given in finding literatures which were directly or indirectly related with operations of various features of “Space Syntax” software. In gist it must be said that the idea of the literature review was to know the boundary of existing knowledge on “Space Syntax” system. The factors counted for deciding the boundary of knowledge were as below:

- Availability of similar researches (Garments Factory Analysis) conducted earlier
- Paper works on more add-ons or plug-ins to the space syntax system
- Factors other than building plan (Material, combustibility, use of signage and maps etc) that may contribute towards determining the scale of a disaster.

Literatures mostly sourced from internet were reviewed for the dissertation. Few of the prominent literatures reviewed may be as below:

- A Space Syntax Based Model in Evacuation of Hospitals - Alper Ä UnlÄu, GÄokhan Ä Ulken and Erincik EdgÄu

- Space Syntax in Architectural Design - Pelin Dursun , Faculty of Architecture, Istanbul Technical University
- Solution for Visibility, Accessibility and Signage Problem via Layered Graphs - Sheep Dalton, Ruth Dalton
- Walk ability Movement and Safety for the City of Berkeley
- Spatial Logic of Morphological transformation

5.3.1 Short Notes on Literature Review (Space Syntax System)

This sub-chapter shortly describes the gist and findings from literature reviews. As the topic still has multiple dimensions within its own linearity, the literature reviews are presented separately for ease of understanding.

In the literatures “A Space Syntax Based Model in Evacuation of Hospitals” - Alper Ä UnlÄu, GÄokhan Ä Ulken and Erincik EdgÄu and “Space Syntax in Architectural Design” - Pelin Dursun , Faculty of Architecture, Istanbul Technical University; the researchers have directly dealt with the parameters set and operable by architectural elements. In the literature titled as Solution for Visibility, Accessibility and Signage Problem via Layered Graphs - SheepDalton, Ruth Dalton; the authors have distinctly pushed the limits of capacity of space Syntax Depthmap in terms of its analyzing capacity of a given drawing. They have discovered some formulas which can be used to integrate the signage and map system in a space syntax analysis.

5.3.2 Gist of Specific literature reviews (Space Syntax System)

A Space Syntax Based Model in Evacuation of Hospitals by Alper Ä UnlÄu, GÄokhan Ä Ulken and Erincik EdgÄu

Although no direct case study on design of RMG factory could be found, few important literatures with similar case studies were reviewed. The literature titled as “A Space Syntax Based Model in Evacuation of Hospitals” by Alper Ä UnlÄu, GÄokhan Ä Ulken and Erincik EdgÄu is apparently the closest one to the topic chosen. Here the researchers conducted a study on hospitals evacuation system. The researchers conducted this study to determine a set of parameters for safe design of hospitals from the perspective of evacuation during emergency. The General Surgery Building, Medicine Faculty, Istanbul University was chosen as the site for the case study. The aim and focus of the study and the rationally for choice of the site is charted below

Table 13, Summery of literature review “A Space Syntax Based Model in Evacuation of Hospitals”

Aim	Examines the exemplary emergency hospital evacuation systems and presents a model related to the spatial, ergonomic and perceptive parameters.
Focus	evacuation of complicated buildings
Reason for Choosing the Site	Complexity of Project Perception Security Complex Spatial Appearance

Parameters considered for the study

- Geometry of the building
- Circulation system of the building
- The cells or spaces around the route
- Physiological system of potentials such as perception or competence of the occupants

The method followed by the researchers to conduct this research was unique and specific for this kind of structure (RMG falls in the same category). The parameters counted for determining the method of this research is bulleted below:

- Crowding of the spaces
- The competence of the occupants
- The spaciousness of spaces
- The integration value of the space
- The visibility area of the occupants
- The distance between egress point and the space.

In this research, crowding at various places within the complex was taken as a prime consideration. The same may be true for RMG factories as the population load may vary at different functional areas. The level of understanding of spaces by various types of users, generally categorized as staffs, visitors and patients were taken into consideration as the perception and response on the same incidence and place may be different by each of this group. The spaciousness of spaces was also taken into consideration. An integration value for the spaces was also tagged. Among other most important parameters considered for the study were “**the visibility area of occupants**” and “**the distance between egress point and the space.**”

Findings/ Shortcomings

This method can be used as a tester for the architects to evaluate their designs according to emergency or disaster cases. Thus, the architect can consider:

- implementing passive preventions
- Revise the functional distributions and the distribution of queuing crowd.

In this research, it is exposed that, although the distance from the starting point to egress point may quite be within the limits of existing standards and codes, the results may not be sufficient enough to avoid vulnerability. The main reason of this situation may be the relationship of the functional usage and the dimensional distance to the egress point. The model emphasizes that human factor, geometrical structure and the space syntax inputs are especially effective for the evaluation of evacuation vulnerability.

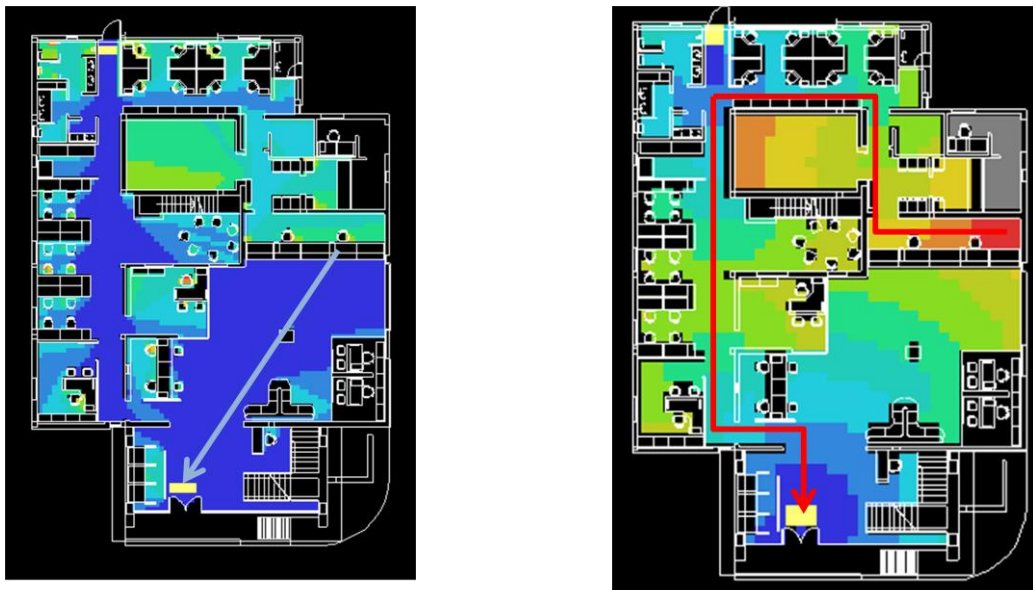


Figure 36, Difference between visibility and metric analysis

To discuss about the shortcomings of this study the following points may be quoted

- it did not consider the specific use of individual spaces
- Specific population load of individual spaces
- The partition wall material or its opacity was not considered in detail

Space Syntax in Architectural Design - Pelin Dursun , Faculty of Architecture, Istanbul Technical University

This paper is a compilation of implementation of space syntax software in three different scenes. It can also be called as a compilation of three case studies uniquely chosen. The paper contains space syntax analysis of three wings namable as architectural education project, practice project and urban design project. The titles of the projects along with their category are given below.

1. practice (Proposal for Extension to Tate Britain)
2. architectural education (Principle Project in British Museum, MSC Course, UCL), and
3. Urban Design Project for Trafalgar Square)

As in extreme relevance with the research topic, only case studies 1 and 2 are reviewed here.

Paper investigates the research theme by focusing on the following points:

1. Design activity itself, its nature and architectural design process
2. Space syntax itself, its main idea and its role in architectural practice.

Tate Britain

- A study on circulation system of Tate Britain was conducted for extension purposes of the exhibition space. Space Syntax Depthmap was used to simulate the real life situation in computer. When a simulation on existing layout of the exhibition space performed based primarily on routes of 100 people for the first ten minutes of their visits, it gave outputs conclusive to bulleted points as below.
- Some spaces in the museum are much more visited than others
- Visitors tend to move along the central axis from the main entrance and intensify especially on the left side of the building
- Visibility graph analysis confirmed this characteristic by simulating the observed visitor movement.

After this three scenarios were created and evaluated by the software to discover the one which balances the load out all over the museum. The scenarios are illustrated below.

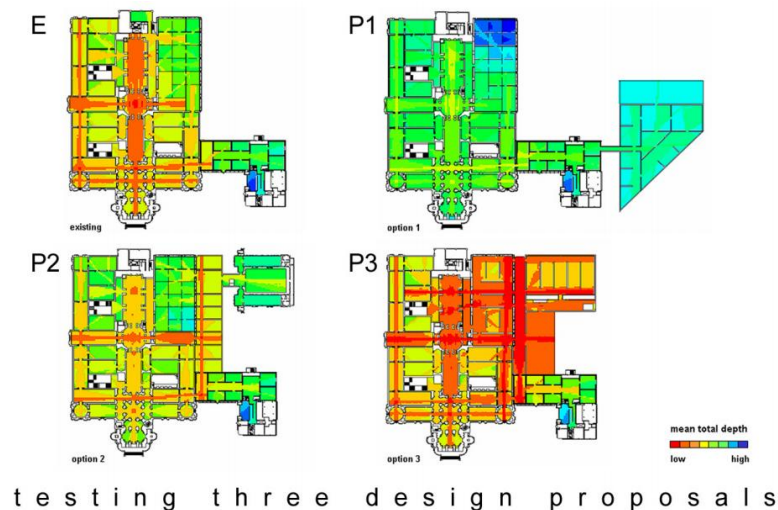


Figure 37, Study of Tate Britain (Dursun, 2007)

In the above illustration it can be seen that the option titled as P3 provided the best solution for design purposes and the museum was modified accordingly.

Analysis/ Shortcomings

Although here space syntax has been used and utilized up to a great intend, few more plug inns could have made the research more authentic and fruitful. The plug-ins as mentioned here is

elaborated in the later literature review titled as Solution for Visibility, Accessibility and Signage Problem via Layered Graphs - SheepDalton, Ruth Dalton.

British Museum

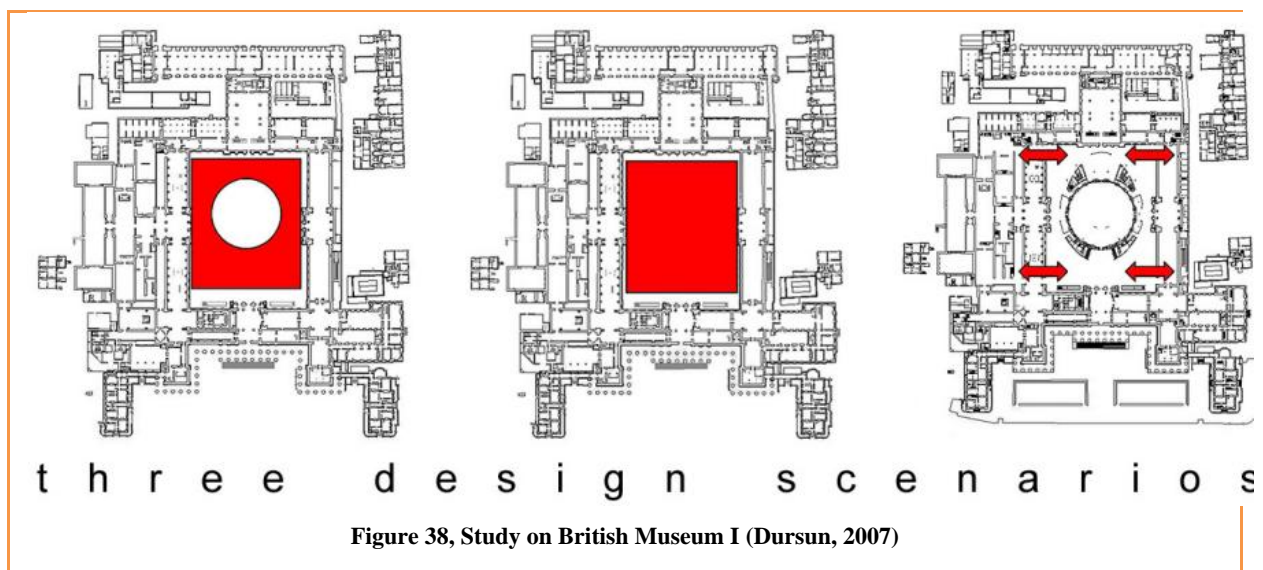
Like Tate Britain, here also space syntax depthmap has been used in an even sensitive scenario.

Here the researcher predetermined some questions for which the answer was sought via research.

The research questions were as below:

- Can one influence the sequence of movement throughout the museum by reconfiguring the spatial morphology of the Great Court? and
- To what degree does the spatial configuration of the Great Court affect the movement flow through the galleries?

Three scenarios were produced by the computer and the best solution was searched for. The scenarios are illustrated as below.



Scenario A reflects the original layout of the museum before the Foster's intervention

Scenario B proposed to remove the reading room by providing bigger open court without any closed space inside.

Scenario C reflects the idea of preserving Foster's proposal by opening new entrances from the great court towards the galleries

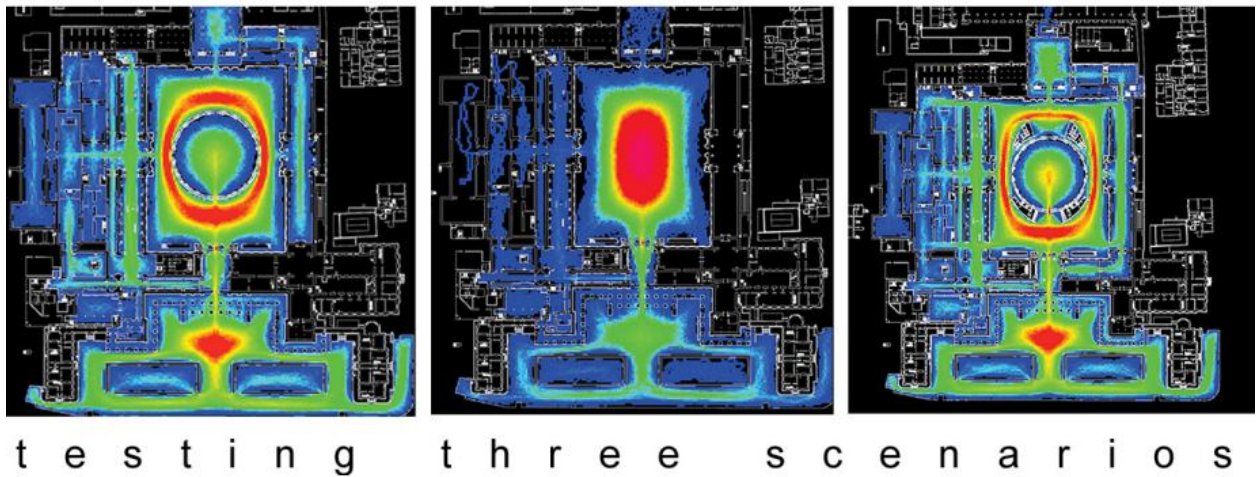


Figure 39, Study on British Museum II (Dursun, 2007)

Findings / Shortcomings

These analyses showed that the most intelligible spatial layout appears in scenario C. This scenario was the most well performed alternative among the three and this was also confirmed by visual graph simulations conclusion the significant factors increasing the “intelligibility” of the spatial arrangement seem to be a combination of long axial lines as well as ring structures that allow multiple choices for movement at key locations (Chiken, et al., 2004).

To discuss about the short coming of this research it must be stated that unlike the study for Tate Britain, here there was no mention about sample population or their projected movement for a given period of time. A few more points such as recording time of stay, frequency of visitors per unit time etc. could have further escalated the quality of this research.

Solution for Visibility, Accessibility and Signage Problem via Layered Graphs - SheepDalton, Ruth Dalton

This is a very unique and important literature that was reviewed. The earlier literatures presented in this paper had certain parameters. Unlike other ones, this literature is a work on how to minimize the parameters to the minimum possible level and maximize practicality in the outputs generated by the space syntax depthmap software. In normal mode, under normal operational setup space syntax cannot recognize the difference between an opaque wall and a transparent wall, such as one made of glass and generates the same type of output pattern for both materials. It can be said that until recently space syntax was “material insensitive”. Now with the development of certain formulas, space syntax can be modified to be “material sensitive.”



Figure 40, Some areas are visible but not accessible (Turner, Doxa, O'Sullivan, & Penn, 2001)

Here the researcher has identified four types of spaces or parameters or objects that contribute towards our movement in that specific area. The areas or objects are categorized as below.

- Atrium
- Half partitions, Cubicles, Glass partitions
- Signage
- Maps

The literature rationally explains the difference in reaction and reality that would happen in an atrium or a place with glass partition, cubicles etc. In addition to these, this literature also gives us hint on how the values for signage and maps can be integrated for space syntax depthmap analysis.



Figure 41, Maps and signage play significant role in determining vulnerability (Britton, 2008)

The report is made further wealthy by adding the formulas for Signage and maps inputs in Space Syntax Depthmap. The formula is given below:

$$Dhg(I,j) = Dea(I,j) * b + Dev * (1-b)$$

$$K(N) = k(N,E1) * b + (1-b) * k(N,E2)$$

Analysis / Shortcomings

This paper has introduced the concept of layer-graph and shown how it can be used in space syntax to represent a wide range of conditions including the visibility/accessibility problem and potentiality of signage in buildings. The inputs on signage and map issues still need to be provided in DOS mode by writing formula which is still hectic for many professionals in the related fields. A system to give map and signage issues in graphic mode may make things better than their present status.

5.3.3 Learning from the literature reviews (Space Syntax System)

The literature reviews have opened scopes for learning (specially the boundary of knowledge) and enhancing the scope of work and knowledge for the chosen topic. Few of the learning are bulleted below:

- Earlier researches did not consider specific population load at specific places
- Visitors time of stay at a place is a determinant factor in deciding his or her vulnerability
- Peoples reaction to certain actions may change with change in space configuration
- Building geometry plays a major role in determining vulnerability
- The simulation work may be varied in site for enhancing its authenticity
- Formulas for giving input on material type for partitions are now available.

From the literature review it can be derived that factory floor planning has a major contribution towards determining vulnerability level of workers.

6 SOFTWARE RUNS

A short note about the how the research is conducted is described in the first part of this section.

Brief Strategy

At first AutoCAD drawing of various readymade garments factory were collected. The drawings were converted to dxf²⁶. format and the software runs are conducted. The necessity, process and parameter for converting the drawings to proper format are elaborated in chapter 05. Usually AutoCAD drawings are filled with numerous amounts of layers. Here, for the ease of study only the layers related to studying obstacles on the way for reaching the exit way are kept “on” for the study as other layers may only cause disruption in the study. To keep things simple and straight forward only the “metric distance” output is taken into consideration for writing the final conclusion of each of the case studies. Each of the case studies is represented with seven images. One showing the furniture layout, another showing the angular distance from the exit point and the final one showing the metric distance from the exit point(s).

Projects Chosen

Projects are chosen randomly. Request was sent to designers, factory owners, experts and peers of the researcher to support this dissertation with the material they could. In response, materials of various types were received. Types of material included basic information about factories, flowchart layout, AutoCAD drawing etc. In addition to this one of the factory owners supplied the researcher with a 2.5 minutes video footage of the day when a part of the factory caught fire. The video clearly shows the effect of regular training and rehearsal, which helped the workers to evacuate from the building smoothly. All the AutoCAD drawing could not be analyzed in Space Syntax depthmap for the two following reasons:

- a. Furniture and machine layout were not present in a few drawings
- b. It was not possible to re-format and import the AutoCAD drawing to depthmap because of drawing scale parameters set in the original drawings

Limitation(s)

The study is bounded by various limitations and parameters. A few of these are:

- a. The study and the analysis given here are based on AutoCAD drawings only and may differ from reality.
- b. The projects studied here may be equipped with various emergency situation tackling equipments and materials, which are not considered in for conducting this study.

²⁶ AutoCAD DXF (Drawing Interchange Format, or Drawing Exchange Format) is a CAD data file format developed by Autodesk for enabling data interoperability between AutoCAD and other programs

- c. This study is only to understand the “vulnerability level of RMG workers in Dhaka in the case of Disaster” only from the perspective of emergency evacuation for hazards such as fire.
- d. Evacuation procedure for other types of hazard such as earthquake may differ from the outputs shown here.
- e. Building codes, rules and laws applicable for Dhaka are given priority in the simulations

Depthmap analysis runs are shown in this chapter. It should be noted here that only the two outputs of space syntax depthmap, related to the study is displayed here, the metric step depth analysis and the visibility graph analysis. The studies are conducted according to the step as shown in chapter 5. Four case studies are chosen for the analysis. More case studies cannot be given as drawings of more readymade garments factories along with their floor layout is not available. It is assumed that since preparation of a detail floor layout or machine layout is not mandatory by law, many factory owners do not ask the respective designers to provide them with proper drawings. Also a concerned designer in a telephonic interview predicted two more reasons for such attitude. The reasons are listed below:

- a. Some RMG factories do not prepare the detail floor layout intentionally so that the floor can be later over loaded with workers and machines.
- b. Save the consultancy fees which need to be paid to the consultant.

In such situation only four drawings in direct relationship to this paper were found for analysis. Due to conditions given by the drawing providers, names of the individual projects are not published. Only a generalized location is published here.

Table 14, Summary of case studies

Case Study Number	Project Location	Area per floor²⁷ (sqm)	No. of floors	Total area (sqm)
Case study 1	Mohana, Bhabanipur, Mirzapur, Gazipur	3,100.00	02	6,200.00
Case study 2	Shirichala, Bhabanipur, Joydevpur	4,230.00	03	12,690.00
Case study 3	Savar, Dhaka	1,982.00	02	3,964.00
Case study 4	Ashulia, Dhaka	2,490.00	06	14,940.00

²⁷ Floor area = carpet area + service core, excluding the emergency exit

Case Study 01: RMG factory at Mohana, Gazipur

Table 15, Case Study 01: summary of facts

Basic Facts	
Floor area	3,100 sqm
Floor population	~433
Area per person	7.16 sqm
Gross area per person ²⁸ according to law	10.00 sqm
No. of exits	04
No. of emergency exit ²⁹	04

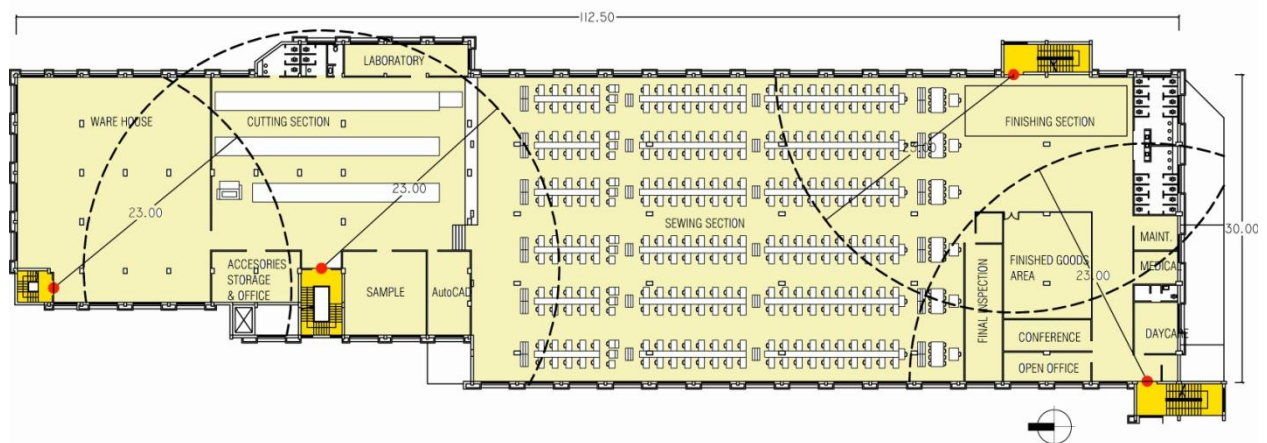


Figure 42, Case Study 01: Floor Plan

The floor layout of Case Study 01 is given above. The floor measures 112.50 m X 30.00 m, totaling an area of 3,100 sqm. The floor has four stairs, all of them isolatable from the floor in case of any emergency. Thus all the stairways can be considered as emergency exit routes. The radial distance of 23 m from each of the emergency exit way is shown. The middle portion of the floor falls outside the radial catchment zone of any of the emergency exits. Sewing section covers most of the floor space. The cutting section sits on the north of the sewing section with the warehouse at the further north. Offices and the finishing section sit south of the sewing section.

²⁸ According to Mahanagar Imarat Nirman Bidhimala - 2008

²⁹ In compliance with Mahanagar Imarat Nirman Bidhimala - 2008 and Bangladesh National Building code - 2006

Table 16, Case Study 01: population density at specific sections

Section	Area (sqm)	Population	Area per person
Warehouse and stores	410	20	20.50
Cutting	408	20	20.40
Sewing	1380	348	03.96
Finishing	212	20	10.60
Office and others	550	25	22.00
Vertical Circulation	60		
Service area	100		

The table above shows the population density at specific sections. The average area per person is 7.16 sqm which is below the gross standard of 10.00 sqm. As it can be seen in the table above the population density in specific sections varies significantly. The sewing section has the lowest area per person, allotting only 3.96 sqm / person, whereas the office section allots 22 sqm. Although the average area per person is 7.16 sqm, there is a high degree of difference in population at individual sections. Throughout the software runs the case study will be evaluated from the perspective of area allotted per person, circulation including length of travel and complexity of egress route.

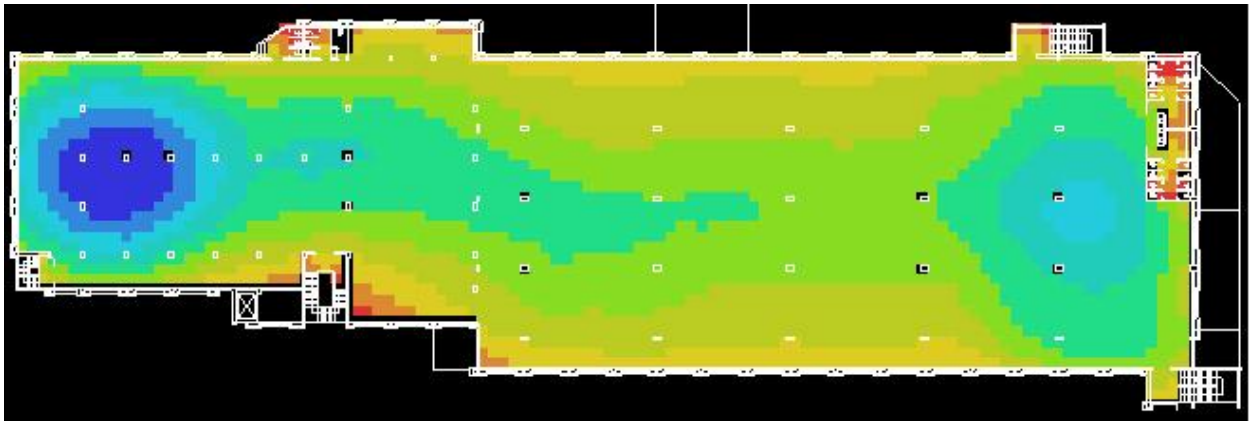


Figure 43, Case Study 01: default metric distance analysis

An open floor, default metric distance graph is shown above. Since there is no obstacle on the floor, the color scheme is mostly in the shades of blue and green, suggesting no or very little risk zones over the floor.

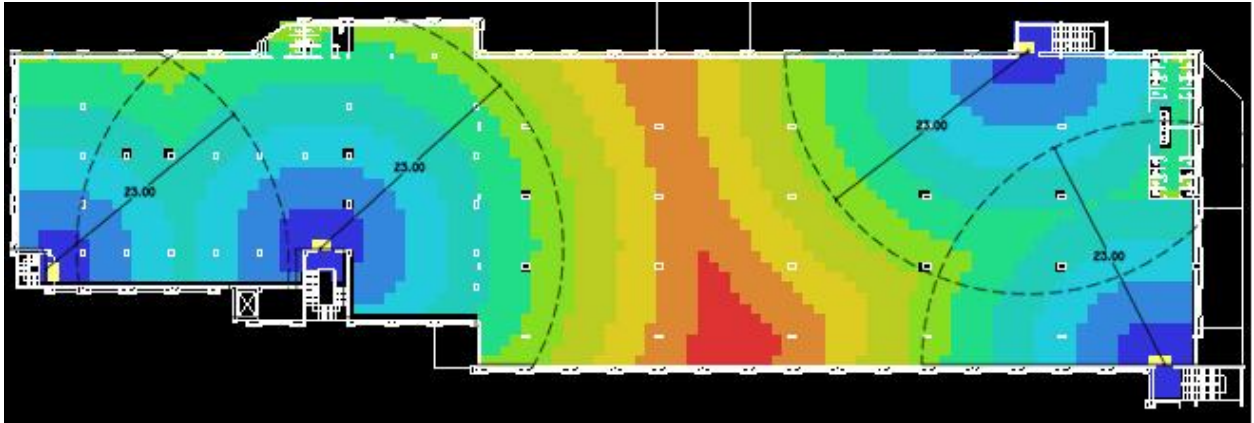


Figure 44, Case Study 01: open floor metric stepdepth with visibility graph set to 23

The open floor plan is studied here. The input radial distance for metric analysis is set at 23 m. here it is clearly evident that the middle portion of the floor is outside the 23 m radial range of the emergency exits. All the areas outside the safe radius of the egress point are shown in shades of yellow (comparatively least vulnerable areas) to red (most vulnerable area).

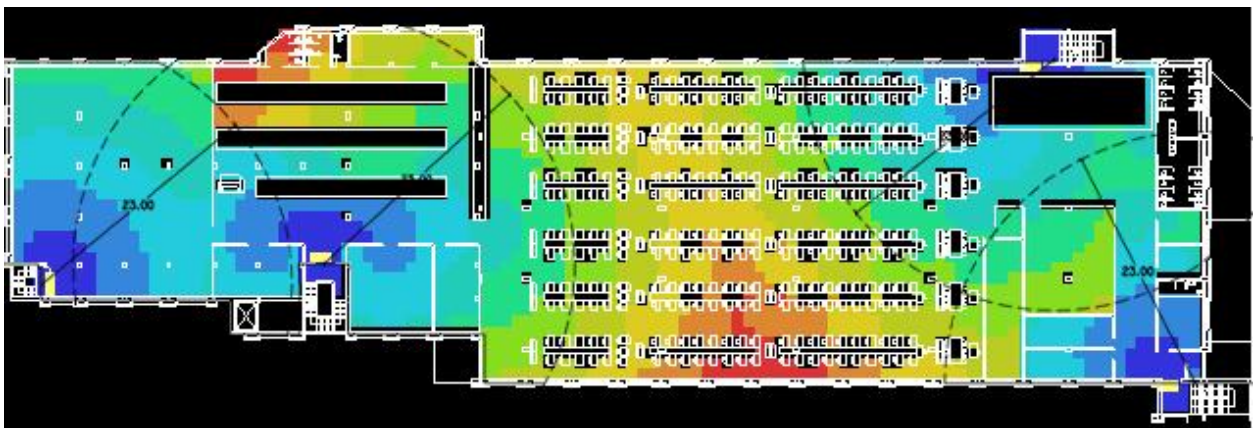


Figure 45, Case Study 01: metric stepdepth with furniture and machine layout

In the illustration above, all the emergency exits are selected as egress routes and the visual restriction is set at 23 m. The simulation marks most part of the sewing section in the shades of green gradually changing to yellow and finally to red at the center-east portion of the floor, indicating the increase of vulnerability of the people working at the center-east portion of the floor.

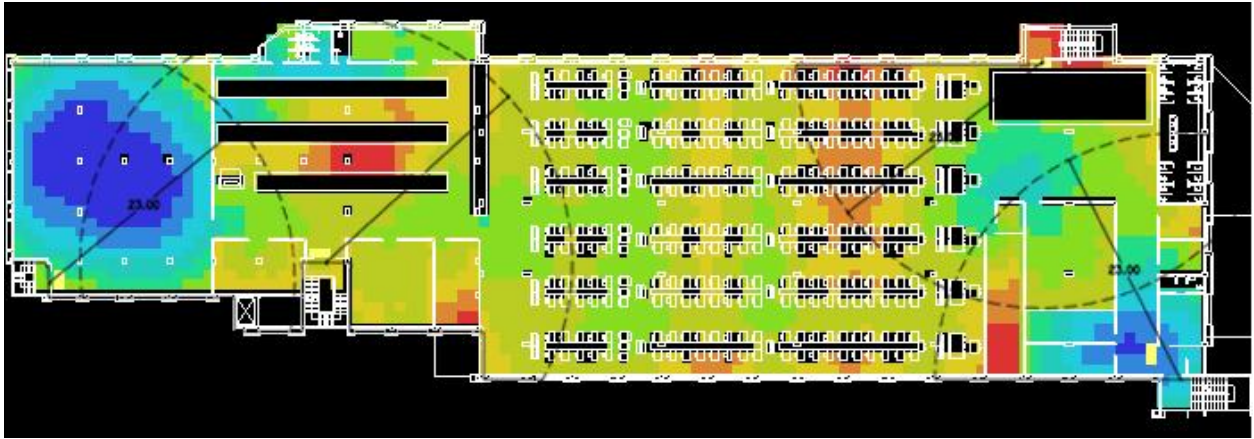


Figure 46, Case Study 01: Visibility graph analysis

The visibility graph analysis is shown above. Here a significant drop of blue shade has occurred. The reason for this might be the sudden high population density in the sewing area. This hypothesis is verified in the succeeding illustrations. The visibility graph analysis gives us an idea on how vulnerable a location on the floor is based on a relative analysis of the whole floor (with visibility parameter set at 23 m). Figure 46 has less amount of blue shade than Figure 45. The reason may be the necessity of too many twists and turns increasing the length of travel from one point to other; and a relatively high population density on the floor.

Problem Finding: From all the analysis shown above the following problems may be hypothesized for this case study:

- a. Length of travel to the emergency exits is higher than desirable
- b. Sudden high population density in the sewing section
- c. Distant location of the emergency exits from the high concentration areas

Probable solutions: Here some possible solutions to the problem of circulation and egress depth to the emergency exits are discussed. As shown in Table 15, in this project area allocated per person on the floor studied is 7.16 sqm against the minimum standard of 10 sqm/ person. Area per person in the sewing section is 3.96 sqm, which is much less than the average area per person over the whole floor. From this it is assumed that if the population density at the sewing section can be reduced, resulting increased circulation space, thus reducing the vulnerability significantly.

Length of travel from emergency exits:

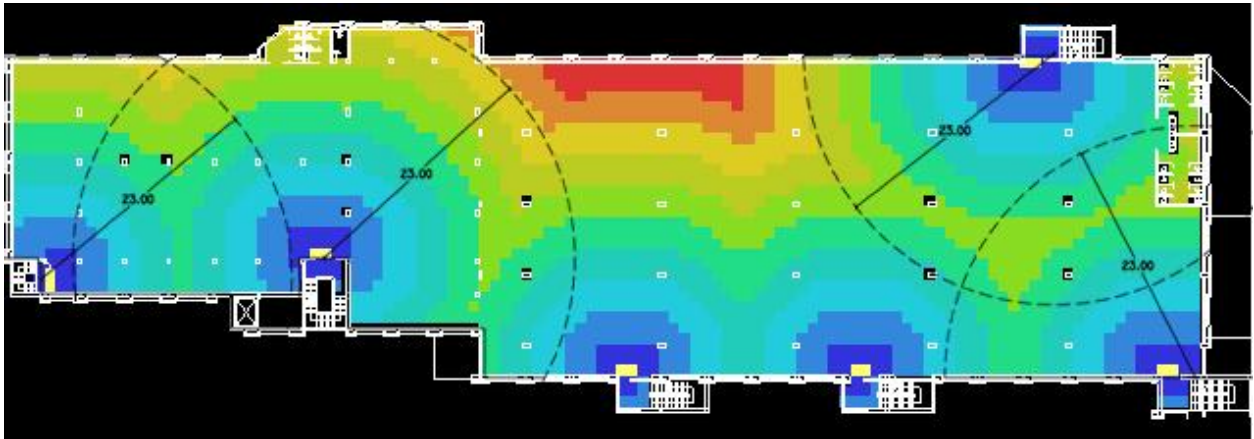


Figure 47, Case Study 01: adding two more emergency exit to the floor

In the illustration above, two additional emergency exits are proposed outside the 23 m radius of any of the original emergency exits. A change in shading than Figure 45 and Figure 46 can be observed. The red shade has reduced significantly. The red shade now exists on the eastern part of the floor, which may also be vanished and replaced by blue shade if another emergency exit is introduced to that part of the floor.

Sudden high population density in the sewing section

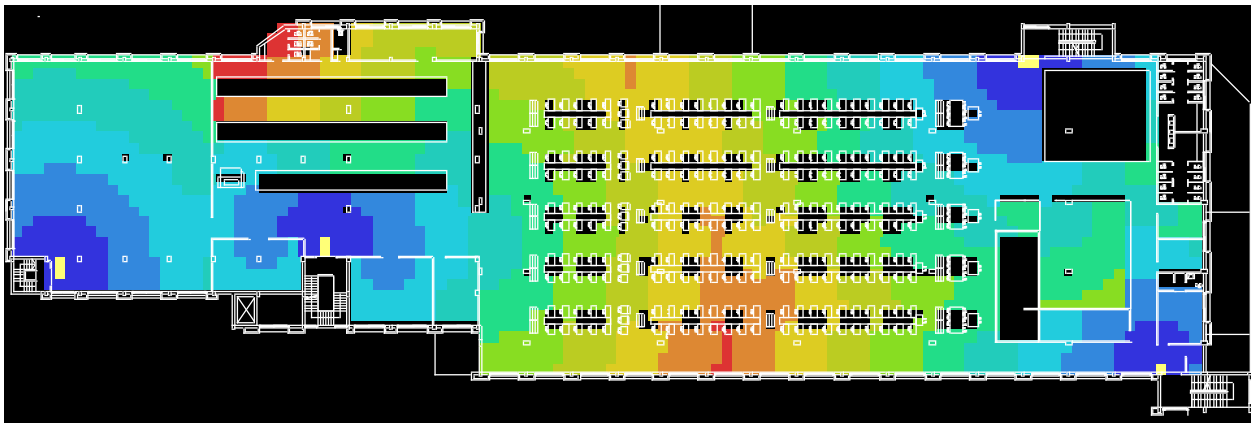


Figure 48, Case Study 01: metric step depth analysis with reduced density

The floor plan has been altered and an analysis is run as above. Here the concentration is reduced at the sewing section increasing the circulation space. The office on the south of the sewing section has been moved 3 m to the east to introduce a direct egress route to the emergency exit on the south-west corner of the building. The shade pattern has changed slightly from the actual situation step depth analysis (Figure 45).

From Figure 47 and Figure 48 it can be assumed that increasing circulation space, decreasing population density in the sewing section and introducing additional emergency exit doors may

reduce the vulnerability of workers in this factory. Based on these assumptions the following modifications are made to the original plan.

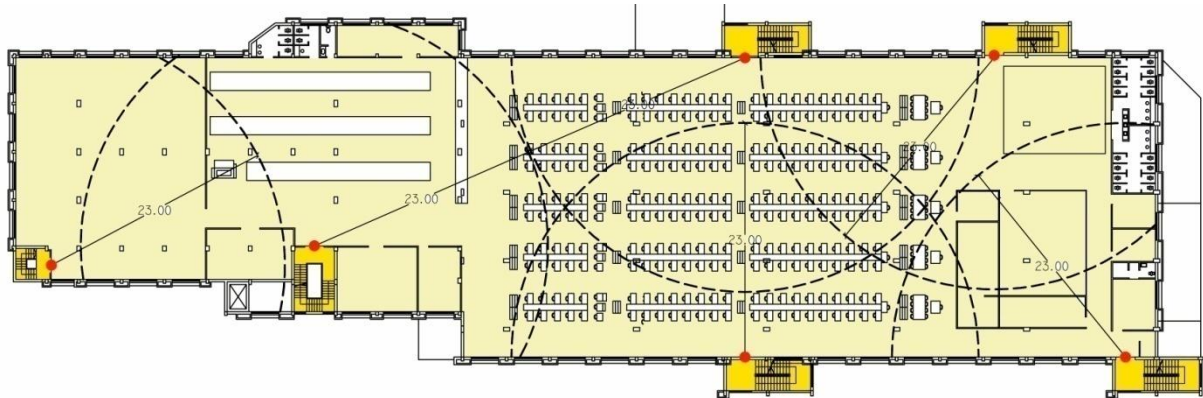


Figure 49, Case Study 01: altered plan

The changes made to the original plan are as below:

- a. Population density decreased in the sewing section
- b. Few of the spaces have been reorganized to ensure flawless crowd movement to egress points.
- c. Additional circulation space created
- d. Additional emergency exits are added

Since the population density in the sewing section was much below desirable range, a column of sewing machines have been deleted. This has created additional circulation space in the sewing section. As originally the core portion of the floor was outside the catchment radius of any of the emergency exits and since the population density is still high at the sewing section, two additional emergency exits are added to the same section of the floor. One exit is added to the east-center edge, the other to the west-center edge. This ensures proximity of the exits to the high population areas. The new exits also have an 180° catchment area making them more efficient than most of the existing ones.

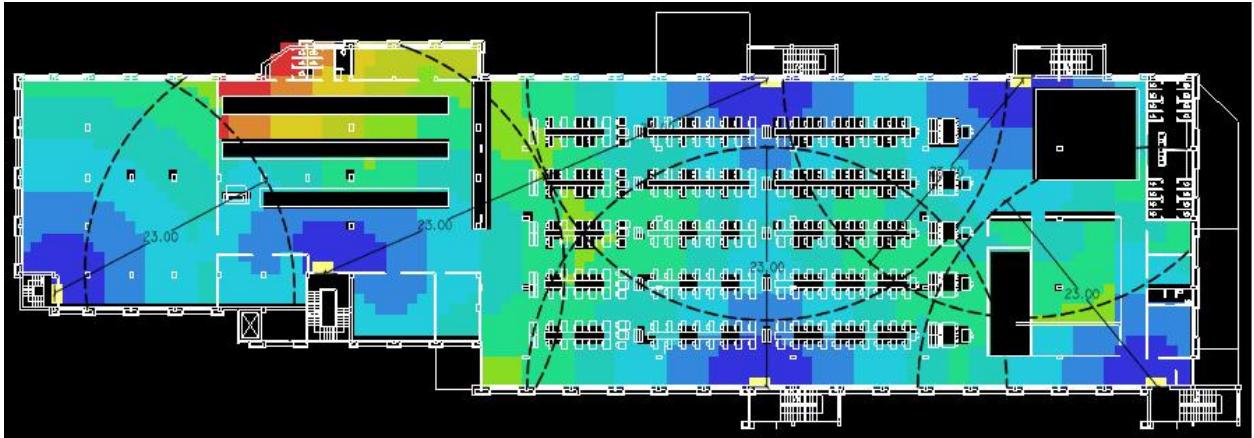


Figure 50, Case Study 01: metric step depth analysis (revised plan)

Final Solution: All the problems and the respective analyses have been accommodated in the simulation above. Here a significant increase in blue shade has occurred from any of the previous analyses.

\Learning: Throughout various steps of analysis of the case study it can be concluded that rather than having the emergency exits at the deep corners of the floor, it may be wiser to have them closer to the central space where the population density is higher. Having the emergency exits at the central part of the floor also increases the catchment area of the emergency exits. The two newly introduced emergency exits are set at both the high density zone and almost at the central part of the floor. This increases the efficient catchment area for the emergency exits.

Case Study 02: Garments Factory at Shirichala, Bhabanipur, Joydevpur

Table 17, Case Study 02: summary of facts

Basic Facts	
Floor area	4230 sqm
Floor population	~448
Area per person	9.44 sqm
Gross area per person ³⁰ according to law	10.00 sqm
No. of exits	03
No. of emergency exit ³¹	03

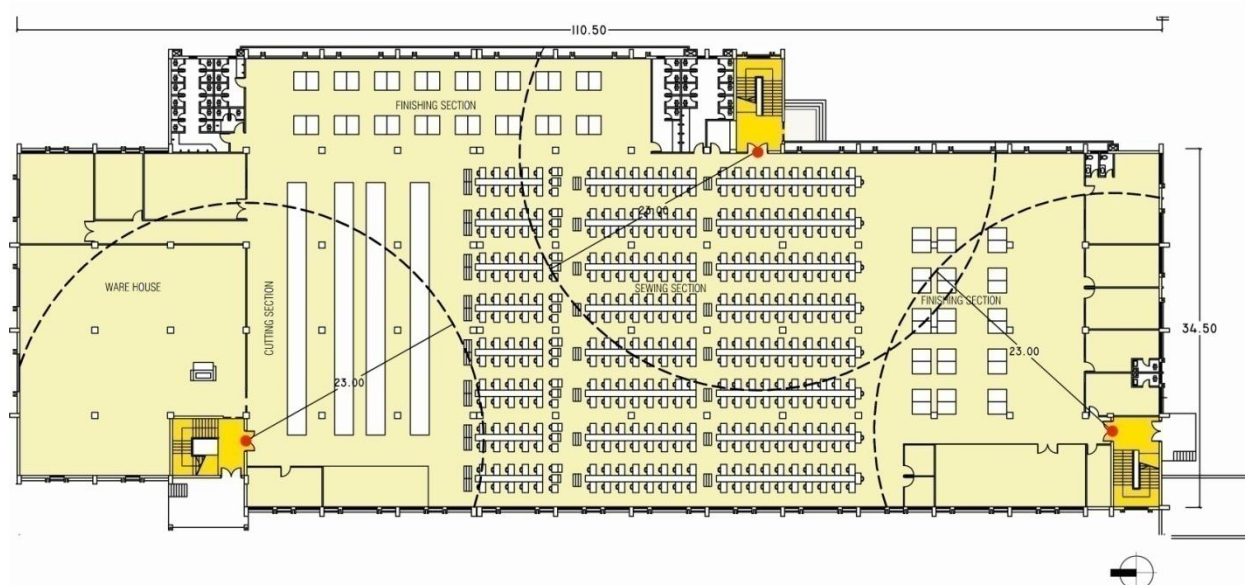


Figure 51, Case Study 02: Floor plan

The floor layout of the case study project is given above. The floor measures 110 m X 34 m totaling an area of 4230 sqm. It has three emergency exits as shown. The radial distance of 23 m from each of the exits is marked. The west part of the swing section and the north part of the finishing section are outside the 23 m radius of any of the emergency exits. Vulnerability of the workers in these areas may be expected. The average area per person on the floor is 9.44 sqm, which is although below the minimum required standard but with a small difference.

³⁰ According to Mahanagar Imarat Nirman Bidhimala - 2008

³¹ In compliance with Mahanagar Imarat Nirman Bidhimala - 2008 and Bangladesh National Building code - 2006

Table 18, Case Study 02: Population density at specific sections

Section	Area	Population	Area per person
Warehouse and stores	510	20	25.50
Cutting	570	20	28.50
Sewing	1420	348	4.08
Finishing	935	50	18.70
Office and others	555	25	22.20
Vertical Circulation	90		
Service area	150		

The table above shows the area allotted per person at specific sections. Although the average area per person is desirable, if area per person at specific locations are considered than the statistic is highly diverse. The sewing section (which sits at the core part of the floor) has a very low amount of area per person (4.08 sqm / person) in relation to any other section of the floor. The cutting section has a very high amount of area allotted per person (28.50 sqm / person) in relation to any other section on the floor.

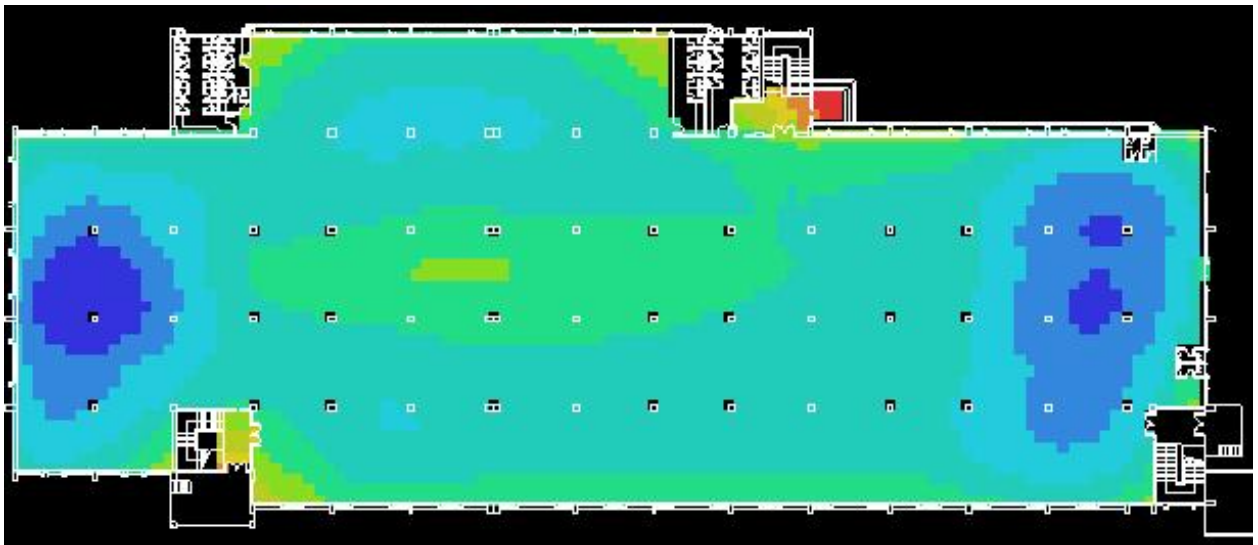


Figure 52, Case Study 02: Default visibility graph analysis

The figure above shows the visibility graph of the open floor area. The whole floor is shaded in blue indicating a safe working environment all over.

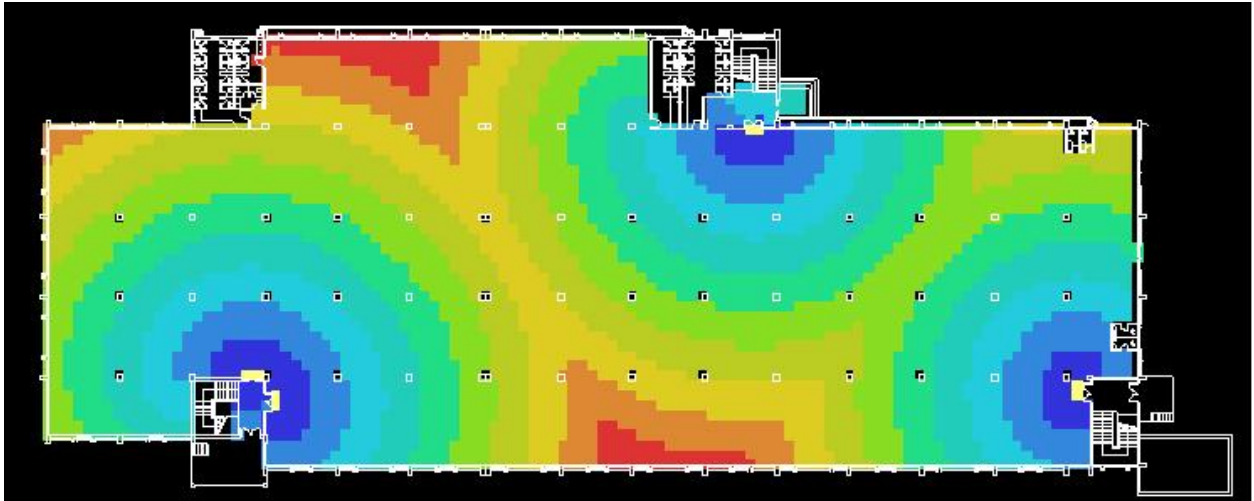


Figure 53, Case Study 02: Step depth analysis from selected location

Step depth analysis is run from the locations marked. The east and west portions of the floor appears in shades of red indicating vulnerability to the workers working in the given areas. It should be noted here that the portions of the floor marked in red are out of the 23 m radius of the emergency exits.

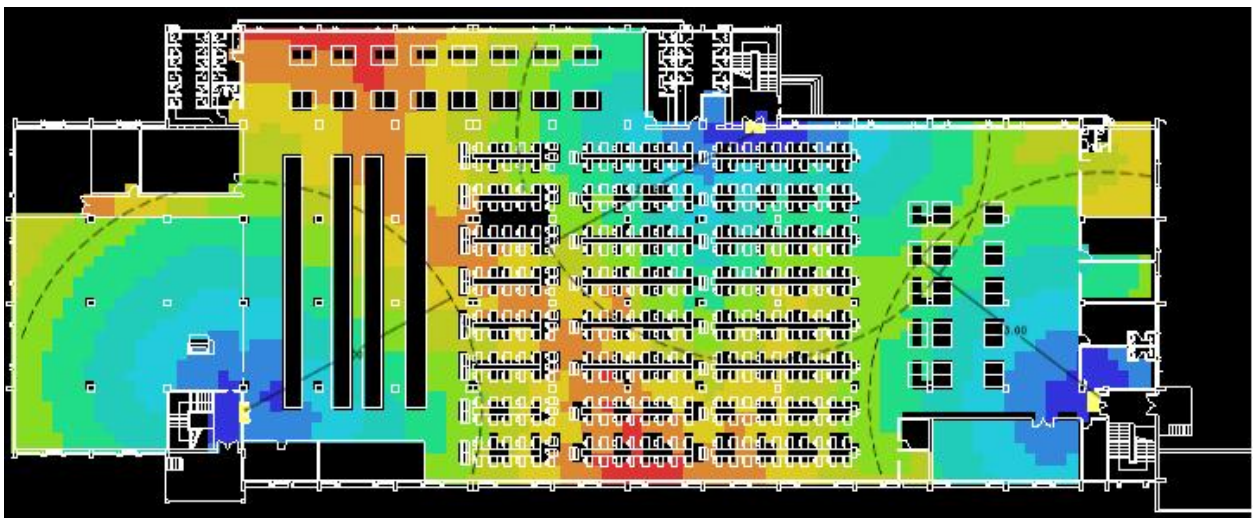


Figure 54, Case Study 02: Metric stepdepth with furniture and machine layout

The metric distance analysis of the case study is shown above. The middle portion of the floor has been highlighted in shades of red. The red strip continues approximately from the east end of finishing section, up to the west end of the sewing section on the core part indicating risk of lives in these zones.

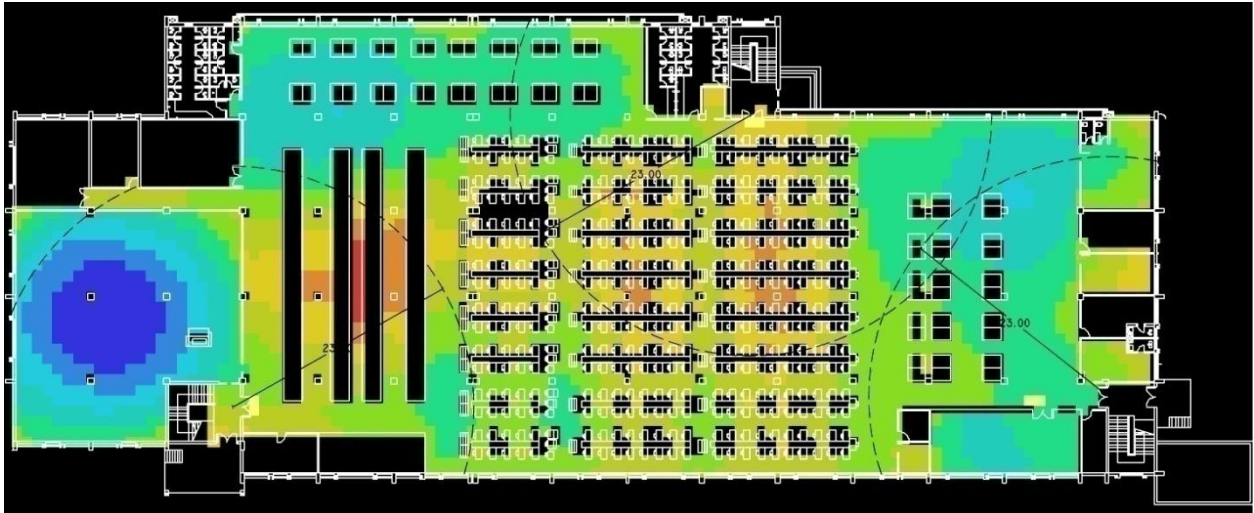


Figure 55, Case Study 02: Visibility graph analysis

The visibility graph analysis is shown above. Although the amount of red shade has reduced significantly in the visibility graph analysis (Figure 55) the amount of yellow and green shade has increased substantially in the core part of the floor. The store on the north end of the floor is given most amount of blue shade as no furniture/ obstacles are shown there. Both the finishing sections at the east and south part of the floor are also relatively safe as they are shaded in blue. Almost the whole of sewing section is in shades of yellow indicating a certain level of vulnerability. High density of machines in the sewing area may be assumed as a reason for such result. Although the floor has almost the same density as allowed by law, most of the population load is concentrated in the sewing section.

Problem Finding: The problems identified in the floor plan are given below:

- A portion of the sewing and finishing section are outside the 23 m radial catchment area of the emergency exits
- Population density is much higher than desirable in the sewing section.
- The circulations to the emergency exits are comparatively narrow.

Probable solution(s): Considering the problems identified the floor plan is modified as below:

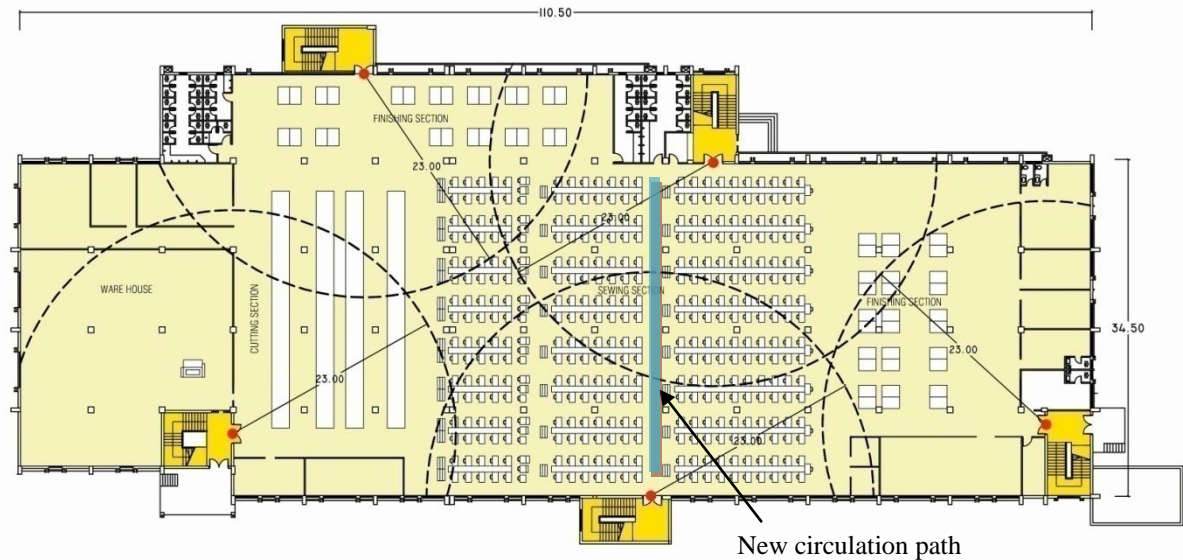


Figure 56, Case Study 02: Altered plan

In the modified plan above two changes as noted below are made:

- Circulation path has been created on the place shown omitting one line of sewing machines
- Two emergency exit ways are introduced on the east and west part of the floor

Adding the circulation space may ease the movement during emergency situation. The additional emergency exits may accelerate the evacuation movements in case of an emergency. The following illustration would further proof these points based on space syntax simulation.

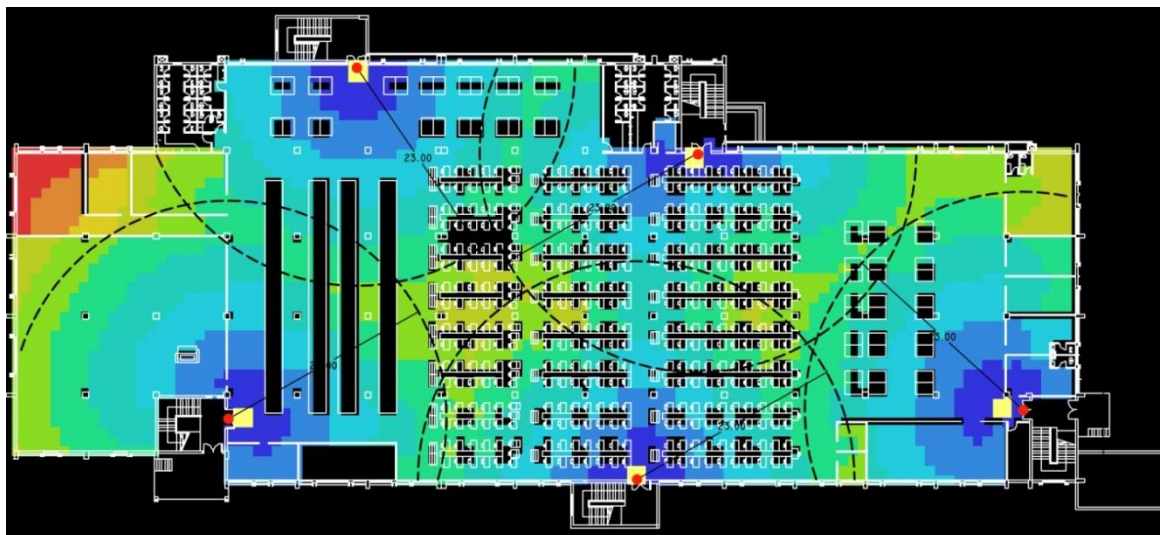


Figure 57, Case Study 02: Revised visibility step depth

The changes in plan as proposed in Figure 56 are put in to simulation and the output generated by space syntax depthmap – metric step depth analysis is shown in the above figure (Figure 57). Here it must be noted that there is a significant increase in blue shade all over the floor. This indicates that the problems identified and the proposed solutions to the problems have matched perfectly for this case study.

Case Study 03: RMG factory at Savar

Table 19, Case Study 03: Summary of facts

Basic Facts	
Floor area	1,982 sqm
Floor population	~280
Area per person	7.06 sqm
Gross area per person ³² according to law	10.00 sqm
No. of exits	02
No. of emergency exit ³³	01

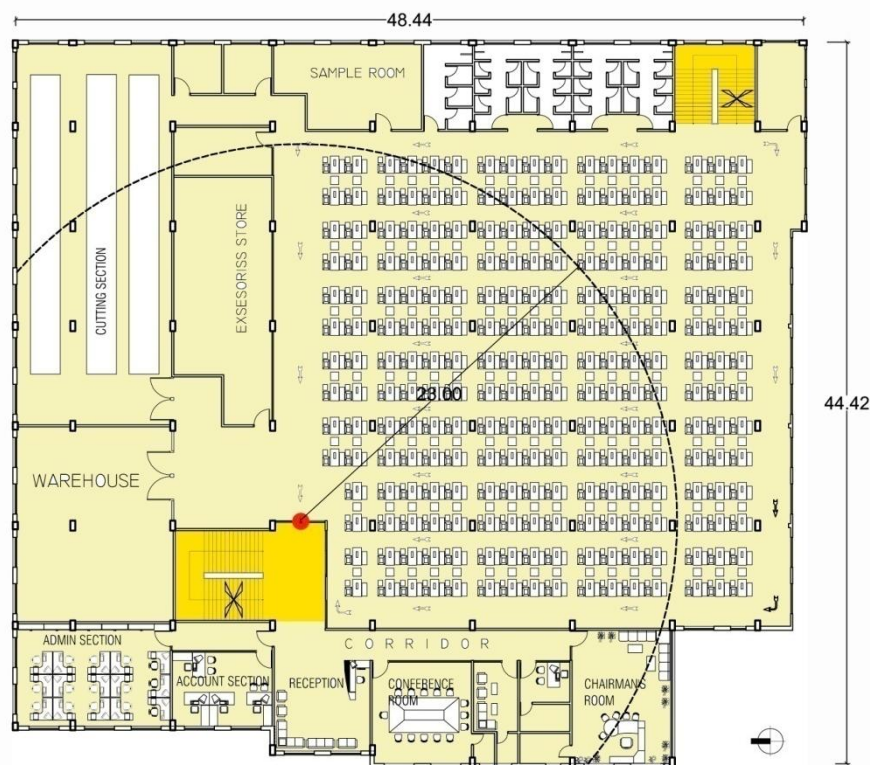


Figure 58, Case Study 03: Floor Plan

The chosen factory is a two storey building. The first floor plan of the factory is given above. This floor houses the cutting and sewing sections, office and warehouse facilities of the factory. The finishing and packing section and the store are situated at the ground floor. Since the population load is higher at the sewing section, so the first floor of the factory is taken for space syntax analysis. Most part of the floors is dedicated as production zone. The office portion of the factory is situated at the west portion. There are two stair cases for access and egress from the floor. The stair on the south-east portion is open. This stair may work as a vertical shaft inviting

³² According to Mahanagar Imarat Nirman Bidhimala - 2008

³³ In compliance with Mahanagar Imarat Nirman Bidhimala - 2008 and Bangladesh National Building code - 2006

fire and smoke to the floor. Thus it cannot be used as an emergency exit. The stair on the north east portion can be isolated from the floor when the door is closed. Thus this stair may be called as an emergency exit.

Table 20, Case Study 03: Population density at specific sections

Section	Area (sqm)	Population	Population per sqm
Warehouse and stores	192	15	12.8
Cutting	217	18	12.06
Sewing	950	224	4.24
Office and others	342	25	13.68
Vertical Circulation	61		
Service area	78		

The table above shows the population density at specific sections of the floor. Unlike case study 01 and 02 area per person is not highly diverse. Almost all the sections have area per person less than what is approved by law. However the sewing section again has the lowest area per person (4.24 sqm / person).

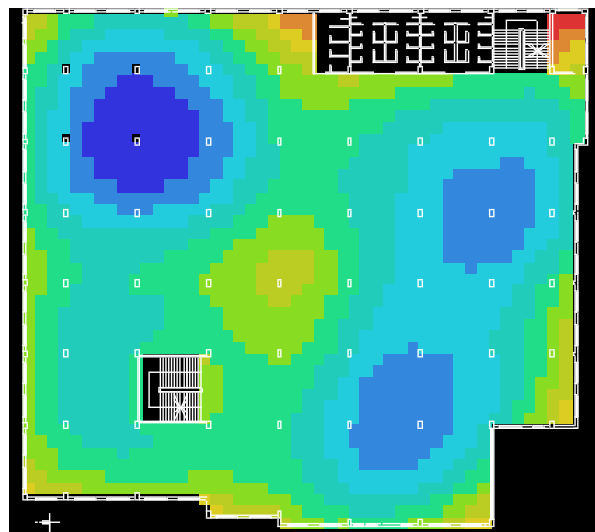


Figure 59, Case Study 03: Open floor visibility graph analysis

The visibility graph analysis is shown above. Most part of the floor is in shades of blue with deep blue concentration at three places, indicating higher visibility in those areas.

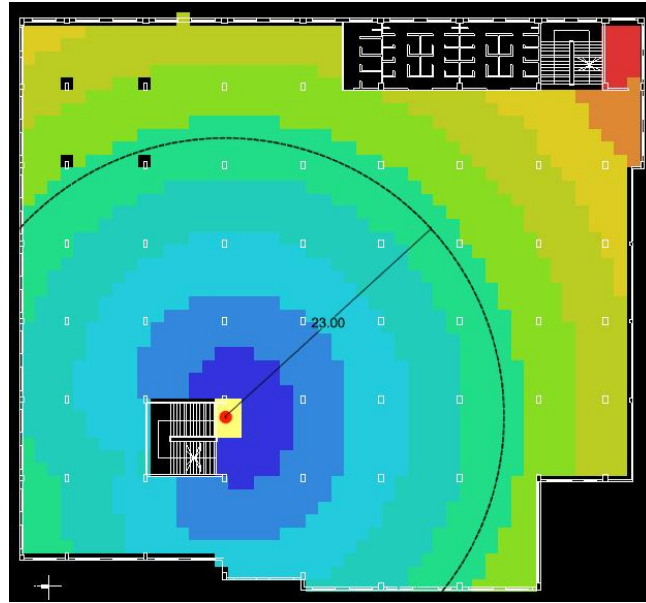


Figure 60, Case Study 03: Open floor metric step depth analysis

The metric step depth analysis with 23 m radius from egress point is shown in the illustration above. It should be noted that the shade is blue up to the radial catchment border of the egress point. After that the shading changed to green then yellow, finally to red at the south-east corner of the floor.

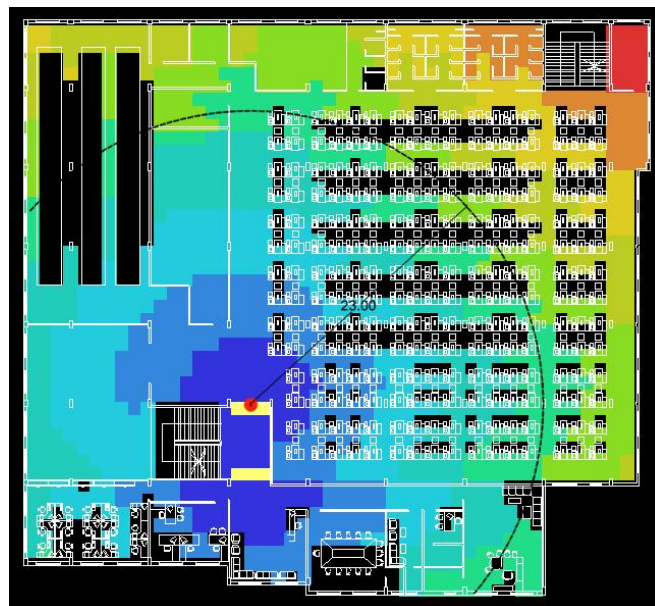


Figure 61, Case Study 03: Metric step depth analysis

The metric step depth analysis graph is given above. The building has two stairs, but since one stair is open, it could not be considered as an emergency stair. Therefore for the default analysis of the existing situation, only one stair (as marked) is considered as an emergency exit. The isovist radius is set at 23m. The analysis shows blue shades up to the 23 m radius. The shade changes to yellow and finally shifting to red on the south east portion of the floor. It is assumed

from the analysis that since the stair on the south-east is not fire rated the workers on that part of the floor has to travel a lot of space to come up to the fire stair on the north-west corner

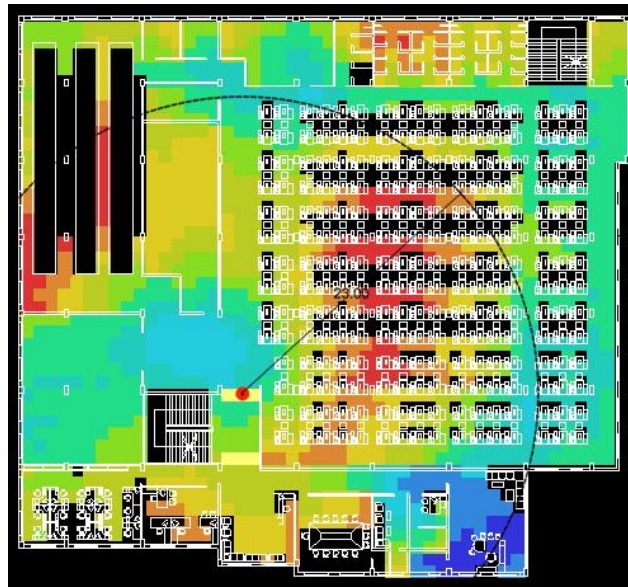


Figure 62, Case Study 03: Visibility graph analysis

Visibility graph analysis of the case study is shown above. The color grading is not as radial as the step depth analysis. Here the center portion of the sewing section is in shades of red. This indicates that although this portion is within the safe radius of the emergency exit, because of the length of travel workers in this area are more vulnerable. The south peripheral sewing blocks are colored blue even though they are not within the safe radius of the emergency exit. This has occurred because of the wider, uninterrupted circulation space along the south and west edge of the sewing section. Even though the south sewing block is outside the safe radius, the length of travel is shorter and simpler than the nearer center part of the sewing section.

Changes proposed: Based on the learning's from the simulation of existing situation, following alterations are made to the original plan



Figure 63, Case Study 03: Altered plan

The plan has been altered as shown above. The stair on the south-east corner has been modified to fulfill all the requirements of an emergency exit. Only three sewing machines have been removed from the floor to accommodate the change.

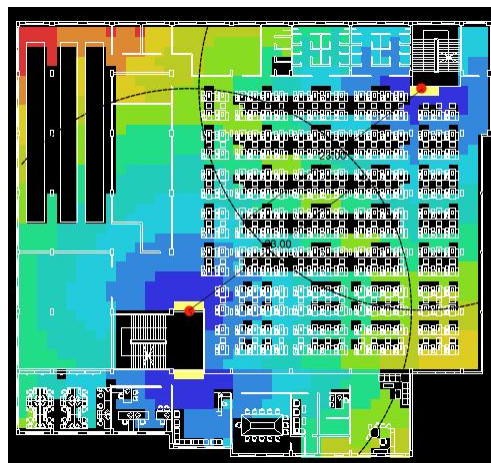


Figure 64, Case Study 03: Metric step depth analysis with altered plan

The metric step depth analysis with altered floor plan is shown above. Here the red shading on the south-east side has been replaced by shades of blue, indicating a safer environment. A reduction of concentration would have further improved the situation. However, as the changes due to reduction of population load and concentration has been simulated in both Case Study 01 and 02, it is not repeated here. One of the targets of this case study was to evaluate if significant change in vulnerability level can be assumed with minimum change in population load, which seems to have been achieved; looking at the simulation result above.

Case Study 04: RMG Factory at Ashulia

Table 21, Case Study 04: Summery of facts

Basic Facts	
Floor area	2490sqm
Floor population	~267
Area per person	9.33 sqm
Gross area per person ³⁴ according to law	10.00 sqm
No. of exits	03
No. of emergency exit ³⁵	03

Case Study 04 is an academic project. This project is chosen to evaluate whether Bidhimala – 2008 or EPZ building rules are practiced in academic projects or not. This case study would also help us to evaluate if safety standards are properly met at academic projects or not.



Figure 65, Case Study 04: Floor Plan

As we can see in the illustration above, the eastern part of the sewing section falls outside the 23 m radial safe distance from the emergency exits. The plan looks cleaner than the real projects simulated earlier. It is evident from the drawing that more space has been left for circulation in this project. Here it must be noted that although more circulation space may ensure better safety, in reality the owners discourage the designers to leave extra space for circulation. The owners prefer extra space for machine units rather than circulation. The floor measures ~83.00 m X 30.84 m totaling to an area of approximately 2490 sqm.

³⁴ According to Mahanagar Imarat Nirman Bidhimala - 2008

³⁵ In compliance with Mahanagar Imarat Nirman Bidhimala - 2008 and Bangladesh National Building code - 2006

Table 22, Case Study 04: Population density at specific sections

Section	Area (sqm)	Population	Area per person
Inspection	375	20	18.75
Sewing	1780	242	7.35
Office and others	60	5	12.00
Vertical Circulation	198		
Service area	75		

In Figure 66 and Figure 67 below the software runs are conducted on the open floor plans of the case study

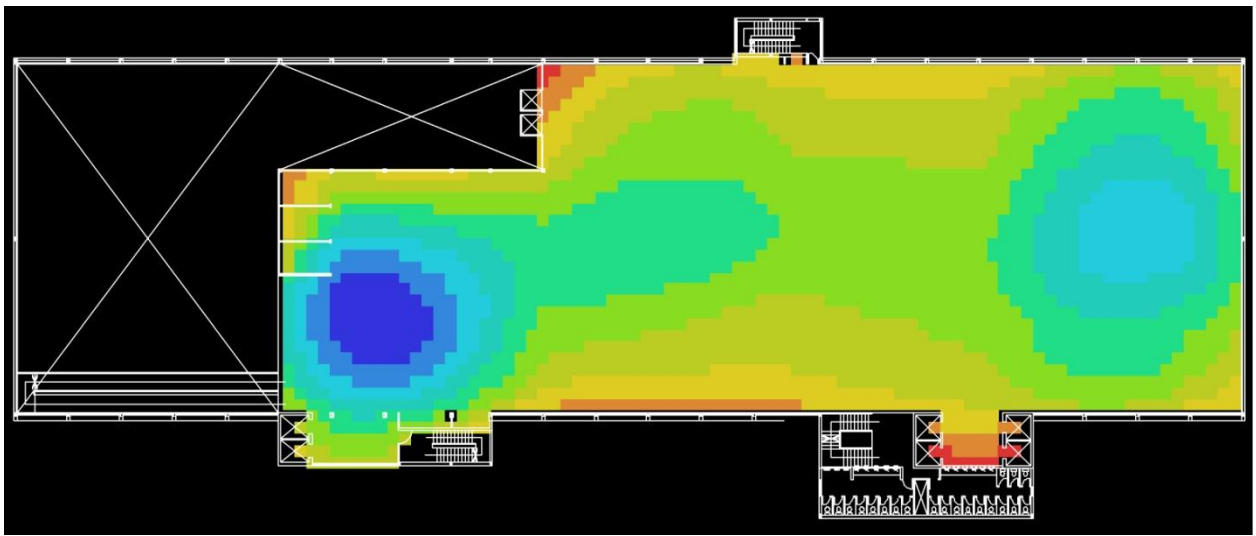


Figure 66, Case Study 04: Open plan, visibility analysis (23 m)

In the above figure the software is run with the parameter of 23 m but without any datum location. The resulting illustration marks east and west ends of the floor as most safe locations and the core portion in a relatively more vulnerable shade.

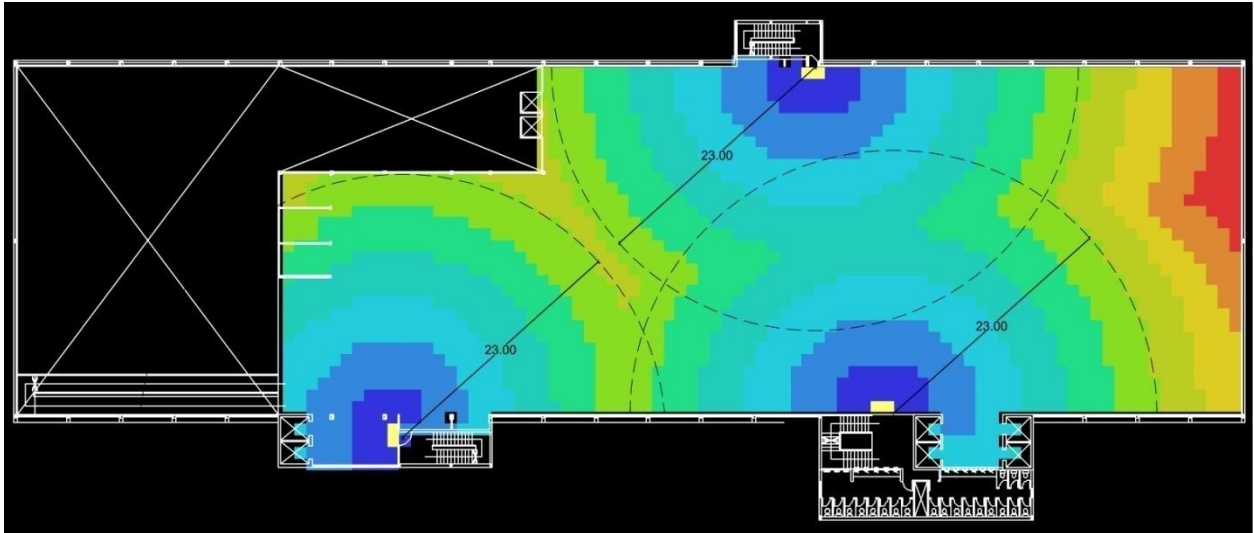


Figure 67, Case Study 04: Metric Step depth analysis of open floor from selected locations

In the above figure the exit locations are marked as shown. The visibility parameter is set at 23 m. The software has generated radial shades based on the points of emergency exit. The core portion of the floor is safe because it falls within the safe radius of both exits at north and south. The west portion of the floor is also simulated to be safe as this portion is well within the 23 m radius of the exit on the west side. The east portion of the floor is more vulnerable as it is outside the 23 m radius of any of the emergency exits.



Figure 68, Case Study 04: Metric step depth analysis of designed floor from selected locations

The analyses in shown in Figure 65 and 66 are run with furniture layer “on” in the graph. Figure 65 shows us the safe and un-safe locations in the plan based on the locations selected and the 23 m radial restriction. Figure 67 is a more realistic version of figure 65. As the furniture layer is “on” the software provides us with additional information (obstacles, which in this case are the sewing machines). Figure 67 was a direct radial graph whereas Figure 68 is significantly different

because of presence of machine layout and for considering relative distances from any point to the next.



Figure 69, Case Study 04: Visibility graph analysis (23m)

Figure 69 shows the visibility graph analysis of the case study. This is a graph generated by default understanding of the software itself. This is a graph to determine the relative level of vulnerability. Depending on specific locations the vulnerability can be higher or lower than what is simulated in Figure 67 and Figure 68. The software has marked the western portion in front of the cutting machines as the safest locations to work and the east end of sewing section as the most vulnerable locations to work. The row shaded in blue can be developed as an emergency exit aisle as this is considered a safe movement route by the visibility graph.

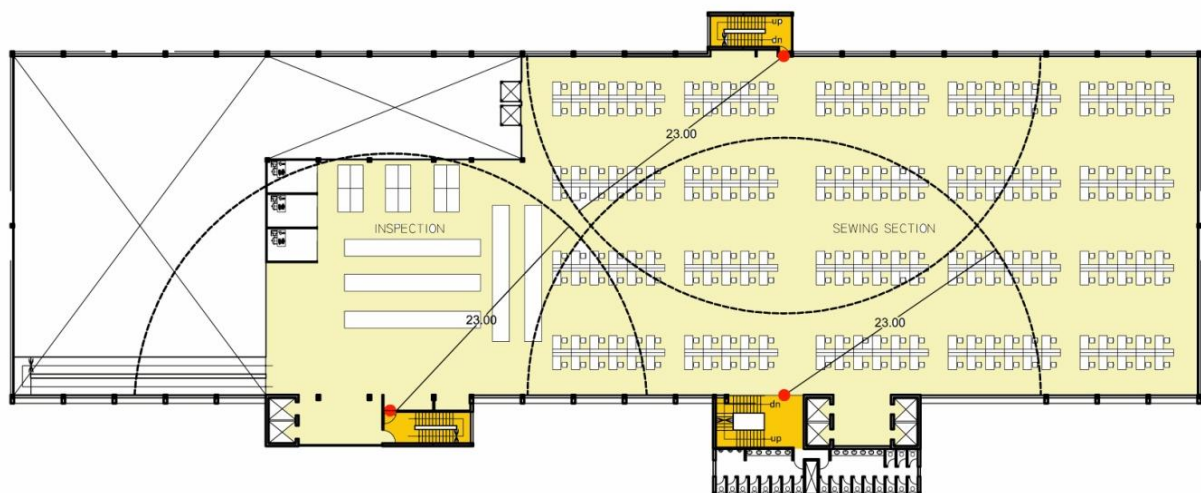


Figure 70, Case Study 04: Altered Plan

Solutions: To reduce the amount of red and yellow shades the following changes are made to the original plan

- a. Every two columns of sewing machines are attached together, giving a common assembly line for both
- b. Rather than having individual circulation routes for each column, one wider circulation path is left for every two columns of sewing machines
- c. The exit on the south-center portion has been moved a bit towards west to match alignment with the emergency exit on the north.
- d. The circulation path connecting north and south exits have been widened

* Here no change in total population load all over the floor is made as both the average population density and the density at specific sections is not highly diverse (Table 21 and Table 22).

*Unlike case study 01, where the visibility graph showed more risks than the metric stepdepth graph, here less risk is shown by the visibility graph than the metric step depth graph. The reason may be that the machine layout is cleaner in case study 04 than in case study 01.

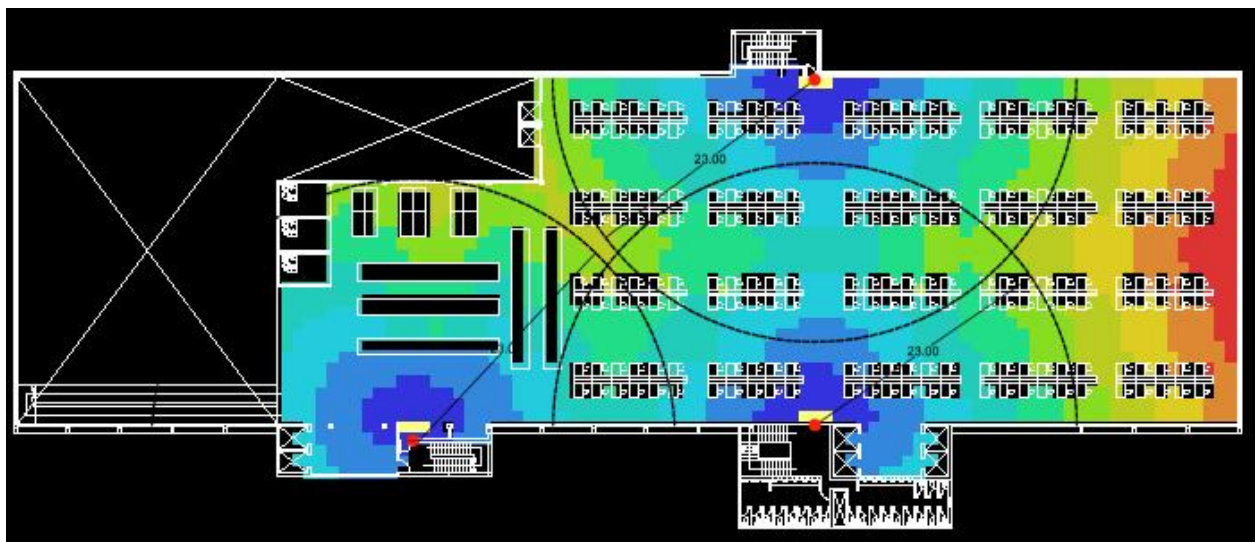


Figure 71, Case Study 04: Metric stepdepth analysis (altered plan)

The analysis was run with all the alterations and the above metric stepdepth graph was generated by the software. Here the blue shade is more focused and well distributed in a radial pattern from the marked exit locations, whereas the blue shade in Figure 68 is not very well distributed.

7 ANALYSIS OF THE CASE STUDIES

This chapter is divided in three parts. The first part point out the determinant factors of vulnerability discovered from the space syntax analysis. The second part titled as “Results of Case Studies” gives a summary of finding from case studies. Graphical representations are used in that section to illustrate the outcomes of case studies. The third part is titled as “Elaboration of the vulnerability indexes and lessons learned from case studies”. This section describes the indexes given to vulnerability factors in the first section. Simultaneously it describes the possible solution(s) to eliminate the individual factors from a factory.

Various findings are made from the case studies above. Many factors for consideration regarding floor design, circulation, population load and location of the emergency exit has been discovered from the case studies which are noted and discussed below:

- A. Insufficient number of emergency exits
- B. Inefficient catchment angle of emergency exits
- C. Improper location of exits
 - a. Exit away from the high concentration zones
 - b. Exit inside ware house
- D. Circulation complexity
 - a. Higher length of travel than desirable
 - b. Obstruction on the way to exit
 - c. Un-designed circulation system
- E. Improperly designed exit way

Results of the Case Studies

Appearance of various types of vulnerability determining factors in individual case studies is charted below:

Table 23, Frequency of vulnerability types in individual case studies

Case Study	Vulnerability Type
Case Study 01	A,B,C,D
Case Study 02	A,B,C,D
Case Study 03	A,D,E
Case Study 04	A,C,D

The frequency of appearance of factors determining vulnerability is shown in the graph below

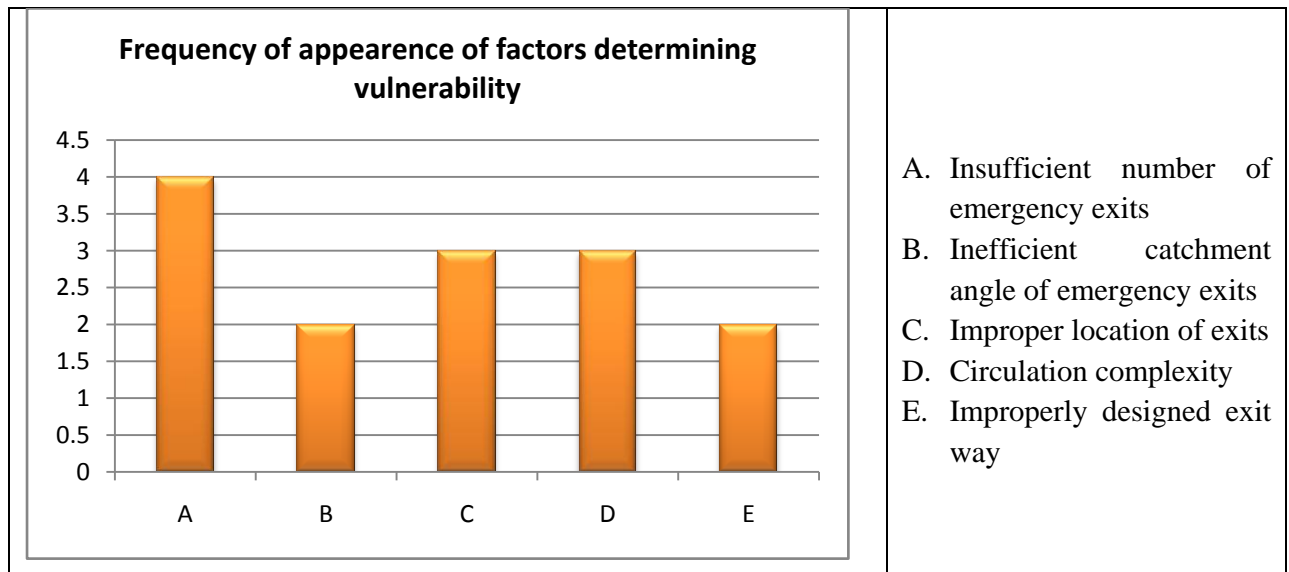


Figure 72, Frequency of appearance of factors determining vulnerability

It can be seen in the illustration above that insufficient number of exits is the prime factors determining the vulnerability of office employees. Insufficient exit is present in all the case studies conducted. Therefore it is called as the prime determinant factor determining vulnerability level of RMG employees. Improper location of exit and circulation complexity is present in 3 of the 4 case studies conducted, making both these, the second top determinant factors of vulnerability for RMG workers. Insufficient catchment angle and improperly designed exit way has appeared in 2 of the 4 case studies, making them both the least appearing factors of vulnerability.

The factors mentioned above are put on a pie chart as below.

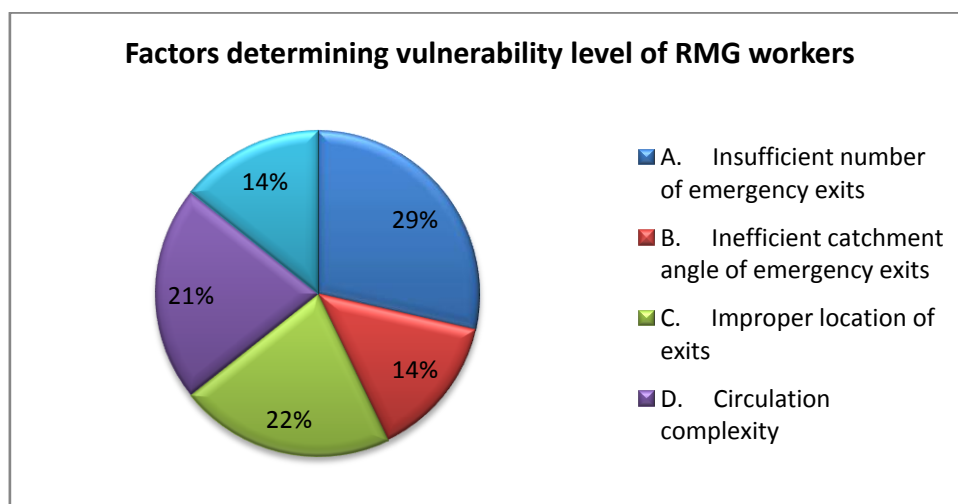


Figure 73, Factors determining the vulnerability of RMG workers

According to the pie chart above, insufficient number of exits counts for determining 29% of the vulnerability of workers in RMG factory. It is seconded by improper location of exits, which counts for determining 22% of the vulnerability, which is slightly above circulation complexity

problem, which counts for 21% of vulnerability. Inefficient catchment angle and improperly designed exit ways count for determining 14% vulnerability each.

Elaboration of the vulnerability indexes and lessons learned from case studies

The points as noted above are discussed below:

- A. Insufficient number of emergency exits: It was discovered from case studies that most of them do not have sufficient number of emergency exits, both from the perspective of regulation binding and from the perspective of practical need.
- B. Insufficient catchment angle of emergency exits: It was discovered in case study 01 and 02 that the efficiency of the emergency exits was significantly reduced by having them at dead corners. Illustrations from case study 01 and 02 are cited below.

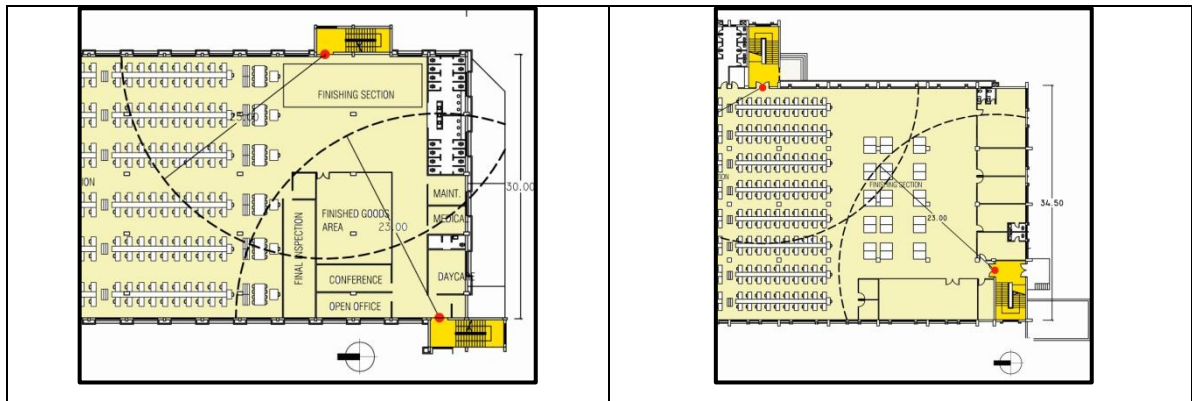


Figure 74, Inefficient catchment radii of emergency exits

Although case study 01 and 02 lacked in having efficient catchment radii, case study 04 had efficient catchment radii. In case study 04, the emergency exits on either side of the sewing section cover $\sim 180^\circ$ catchment radius.

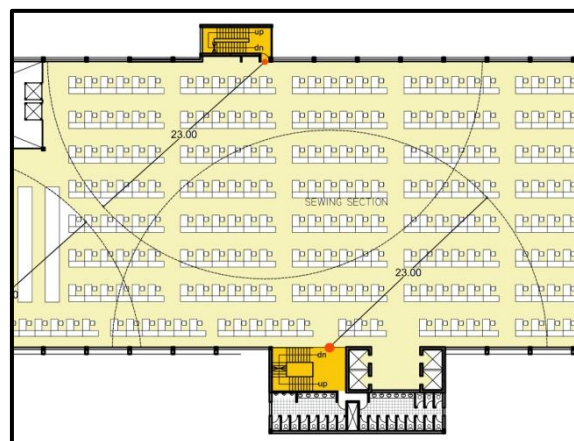


Figure 75, Efficient catchment radii of emergency exit

From this it can be concluded that it is better to ensure that the emergency exits get more catchment angle. Locating them at center or core areas rather than at corners or edges may ensure higher catchment radius for the emergency exits.

C. Improper location of exits: it was discovered that few of the emergency exits in case studies were located improperly. This factor has been divided in two parts:

- a. Exit away from the high concentration zones
- b. Exit inside ware house

It was discovered that the exits were located away from the high concentration zones of a floor. This increases the length of travel significantly making the workers more vulnerable to disasters. In some of the factories possible means of escape was situated inside the warehouse, which is a highly potential area for fire ignition. Just by small changes in design this problem can be overcome.

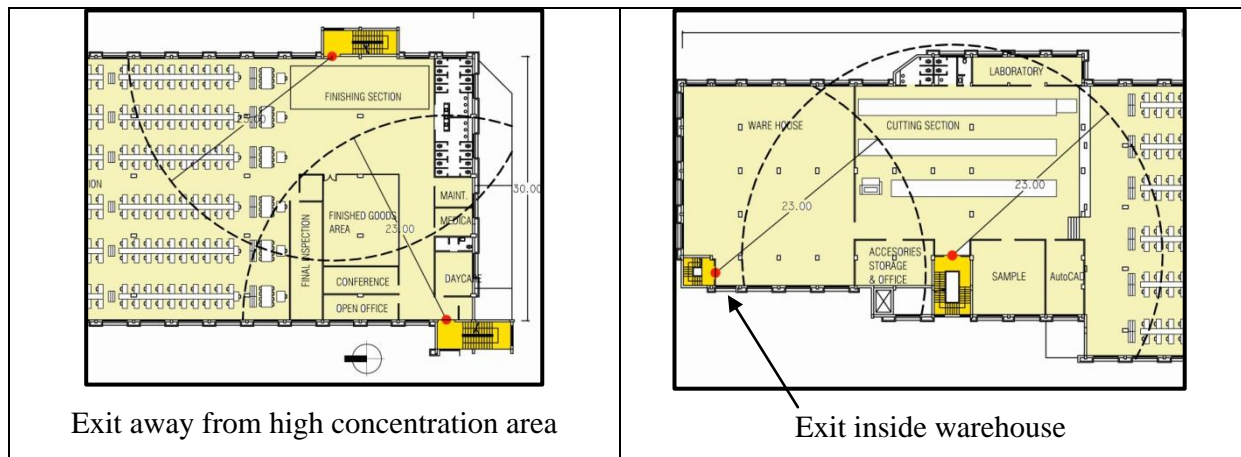


Figure 76, Improper exit locations

The illustrations above are snapped from Case Study 01. In the image on the left it can be seen that the catchment radius of the emergency exit ends before the sewing section, where there are most number of people. Even though the exit meets all the requirements for being an emergency exit (fire rating etc.), it might not work very efficiently as its catchment radius has a very low population density and the length of travel from the sewing section is higher. In the illustration on the left, a possible exit way is located inside the warehouse, where there is less population density. Moreover, an open stair as such may work as a vertical shaft to pass fire from one floor to the next. However, in case study 02 this problem was well addressed.

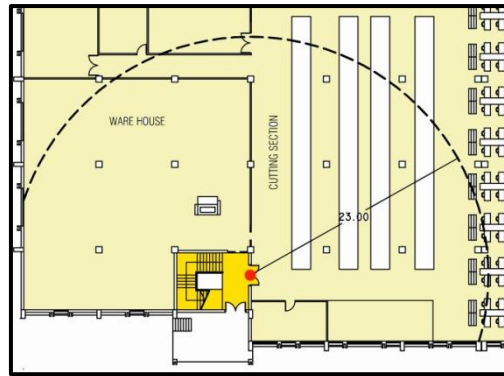


Figure 77, Proper location of exit

The above image is from case study 02. Here the warehouse stair is set towards the core of the building rather than any edge. This provides the opportunity to close the door towards warehouse and keep the door towards the cutting section open to serve as emergency stair.

D. Circulation complexity

Circulation complexity is a major determinant factor of vulnerability. Three factors are discovered to contribute towards circulation complexity, namely:

- Higher length of travel than desirable
- Obstruction on the way to exit
- Un-designed circulation system

These three factors individually or collectively appeared to contribute for creating circulation complexity in the case studies. In case study 03 the length of travel from the core part of the sewing section to the nearest emergency exit may rise up to or more than 50 m. Obstruction to exit point is another major burden as it can be seen in the illustration below.

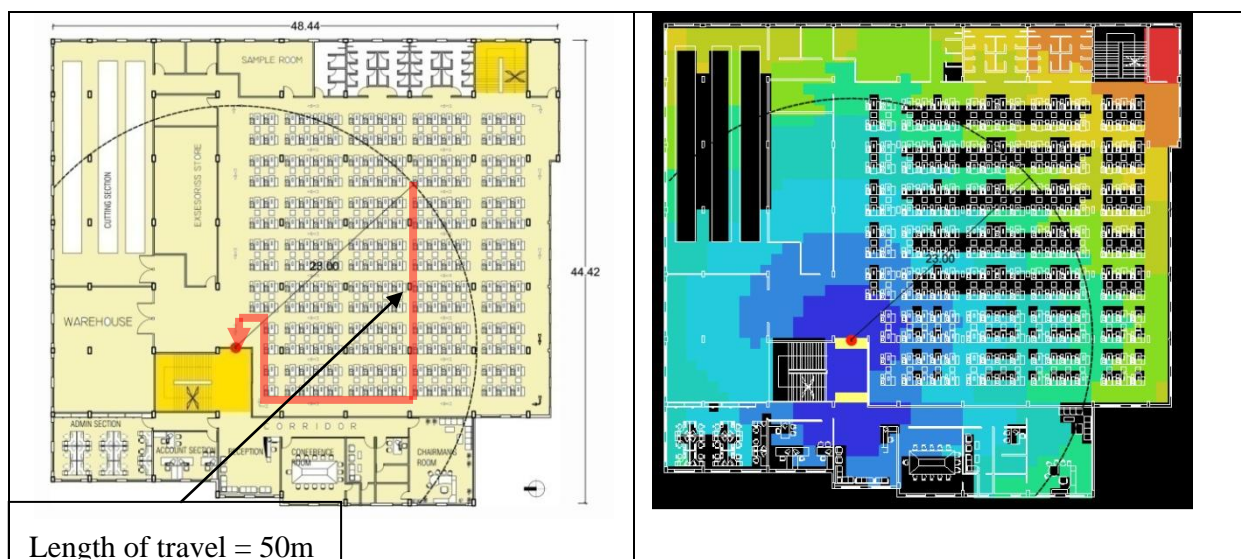


Figure 78, Higher length of travel and corresponding metric step depth graph

Here the length of travel from one of the furthest points within the catchment radius is 30m, which is more than the desirable range. The length of travel can be reduced in many ways. One of the ways is to create additional exit way. This can also be done by modifying existing exit ways to meet the requirements of an emergency exit way. In Case Study 03, the exit on the east is modified to serve as an emergency exit. This has helped to distribute the total population load in two exits and reducing the length of travel from the east part of the floor to the emergency exit. The circulation has been eased by widening it. A few sewing stations are deleted from the front of the exit on the east to accommodate the additional crowd there in case of an emergency.

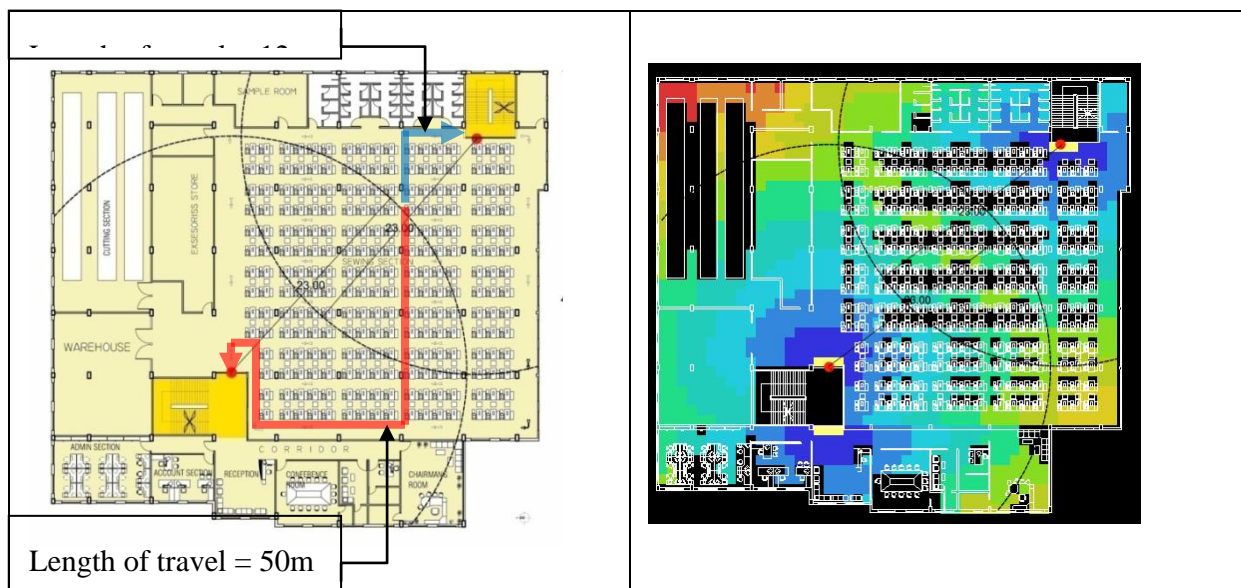


Figure 79, Altered plan and its corresponding metric step depth analysis

Another good example of this kind of problem (Circulation complexity) is Case study 02. Here originally circulation in front of the emergency exit on the east side was not clear, which significantly reduced the efficiency of the emergency exit. Later in the altered plan, a circulation path is created approximately connecting the eastern emergency exit to the newly introduced exit on the west. This significantly reduced the length of travel to emergency exit for many of the workers. In the later simulation both the exits were illustrated to be more efficient than before.

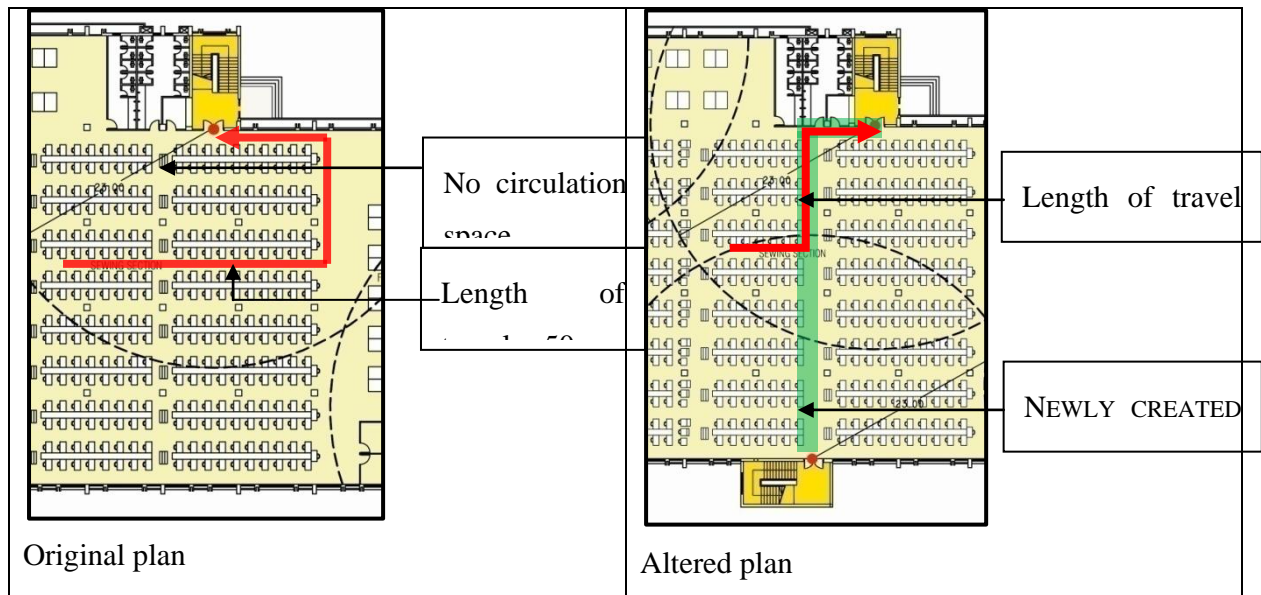


Figure 80, Original and altered plan of core area of Case Study 02

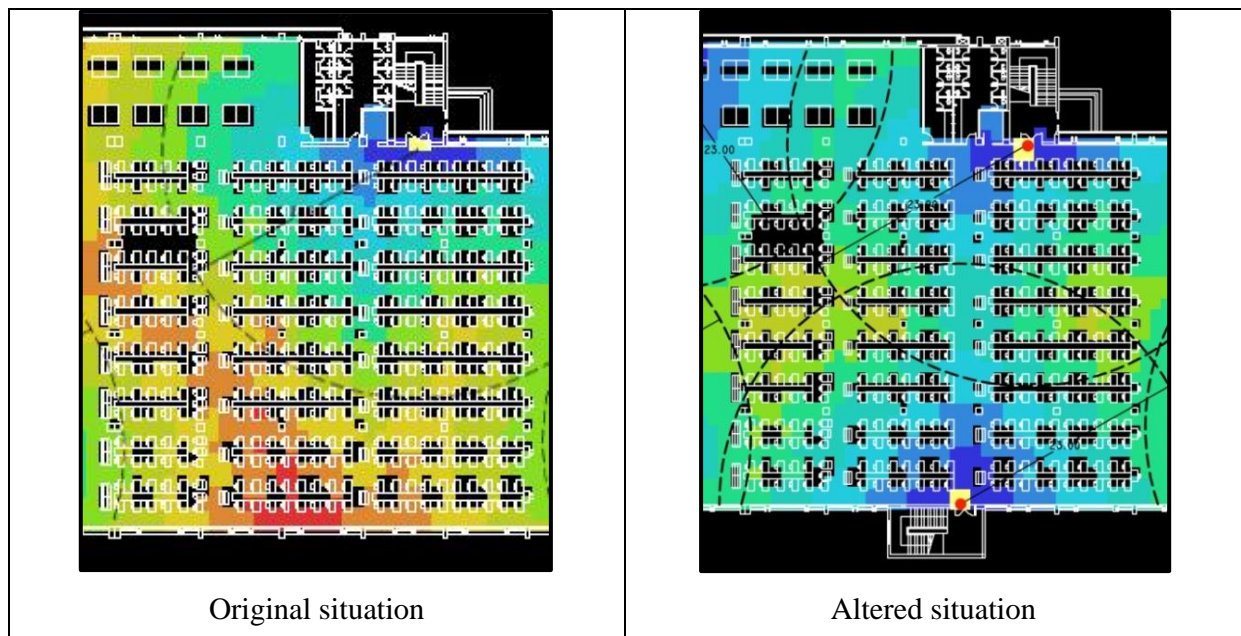


Figure 81, Metric step depth analysis of original and altered plan of Case Study 02 (core area)

E. Improperly designed exit way: In case study 03 and 04 two of the exit points were not properly designed to perform during a fire breakout. Few modifications made to the exits, Keeping their locations same, they can be converted to emergency exits. Original and modified exit of Case Study 03 is shown below:

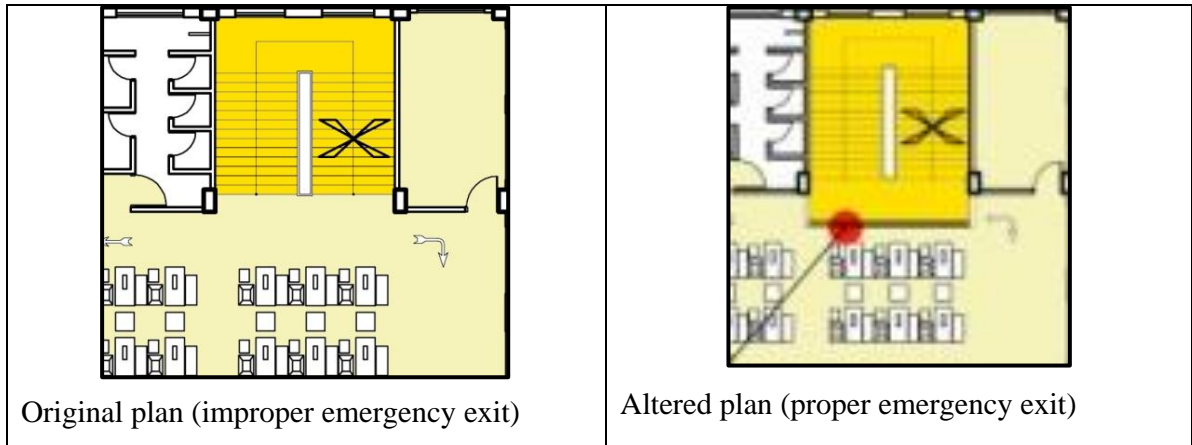


Figure 82, Improper and proper emergency exits

8 CONCLUSIONS

It has been discovered that there are a few triggering points for various events that ultimately result in catastrophic accidents. The reasons for fire and the reason for casualty are identified in the dissertation; simultaneously the need for proper interior design and necessity for proper circulation and location of emergency exit is also highlighted by the space syntax simulations.

Reason for fire: In Section 4.1 it was discovered that in more than 70% of the cases fire was ignited from electrical short circuit. Therefore in the electrical design must be considered as a prime issue of concern while a factory is being designed and constructed.

Reason for casualty (I): Building permissions are given on the basis of open plan. From the analysis it has been discovered that in some cases, the interior design and machine layout causes a massive change in use pattern, circulation system etc. which might sometimes be hazardous for the buildings' users. From the software runs and succeeding analysis it is discovered that higher length of travel to reach emergency exits, small exit size, distance of a point from the exit, high population density, improper location, inefficient catchment angle of emergency exit at RMG factories may be marked as major reasons of vulnerability to RMG workers. Strong efforts to reduce these troubles may reduce vulnerability of RMG factories, elevating them to a higher level of safety.

Reason for casualty (II): It was established in Section 4.5 that the circulation issues contribute largely in determining the casualty level in case of fire in an RMG factory. Stampede and being unable to exit together came up as the major reasons for casualty. In the software runs in Chapter 06 and their subsequent analysis in Chapter 07 worked out that various factors regarding circulation such as length of travel, obstruction on the exit way and un-designed circulation system; positioning of exit such as improper catchment angle, exit away from high concentration zones; insufficient number of exits etc. to contribute towards determining the vulnerability of RMG workers.

To conclude it can be said that management issues and design issues cumulatively contribute towards determining the level of vulnerability of workers in RMG factories. High emphasis needs to be given in electrical design to reduce the chances of ignition of fire. Space syntax depthmap analysis may help designers to solve circulation issues in a way to ensure more smooth evacuation and management needs to ensure regular drill and clear circulation routes to ensure flawless exit in emergency situations.

Recommendations for further research:

Like any other research work there is opportunity for further work in this research. As described earlier, the conclusions above are derived both from the findings of literature review, interviews etc. and from the space syntax analysis of some RMG factory layout plans. There is scope for work in both the wings of the research.

In this dissertation only prime architectural elements such as building plan, population load, exit point etc. has been taken into account. A further research can be conducted with electrical, HVAC or mechanical ventilation system of textile industry. This work may find out how much the mechanical ventilation system may contribute towards causing casualties. In Section 3.1.6 the flammability of different types of textile fabric was discussed in brief. A research can be carried out to forecast if different safety measures are necessary for working with different types of textile fabric.

The software analyses in this dissertation are conducted with default settings and the student version of the software available to the researcher. A further work by actual Space Syntax professionals may result in more concrete solutions regarding emergency exit pattern in RMG factories.

A study can be conducted to record workers actual response and movement pattern in case of emergency situation in Bangladesh (through fire drills and available video footage of actual incidences). The findings of such study may be used to further modify the space syntax simulation system and may help in developing a more concrete code of safety, design and operational management of RMG industries in Bangladesh.

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APPENDIX

1. [Requirements for Self Constructed Buildings in Export Processing Zones, Bangladesh \(Pages 2-7\).](#)
2. [Dhaka Mahanagar Imarat Nirman Bidhimala – 2008 \(pages- 3063-3077\).](#)³⁶

³⁶ Bengali font (Bijoy Karnafuli) is necessary to read the pdf file